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SENSOR PREVIEW IMAGERY (SPI): TARGET PREVIEW FROM OFF-BOARD SENSOR FOR STRIKE AIRCRAFT (U)

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Kenneth R Boff

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13. ABSTRACT *(Maximum 200 words)*

This report describes the development of a concept for obtaining imagery from an off-board sensor that provides previews of the target area. An off-aircraft launched image-transmitting sensor platform, a Sensor Preview Imagery (SPI), would provide the crew with target pre-looks, overlooks and aft looks, thereby providing the aircrew information such as target position, status and defensive counter-measure employment. A land (railyard attack) mission was used to examine parameters for SPI launch points, airspeeds, altitudes, fields-of-view, look-down angles, tactical maneuvers and modes of platform control. Following the system requirements analyses phase, a man-in-the-loop simulation was conducted to refine the derived parameters with crew member input. The simulation study resulted in objective and subjective data for the evaluation of the SPI concept. On average, the optimum attack plan was selected between 53% to 73% of the time. Accuracy varied as a function of the target laydown. The input from the crew members served to refine the man-machine interface and the concept of employment for a non-maneuvering SPI.

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PREFACE

The idea for the real-time, air-launched, autonomous reconnaissance vehicle concept presented in this report was the brain child of the late Col (Ret) John C. Simons, a combat pilot in WWII, Korea, and Vietnam. In 1968 Col Simons, then a Major with the 609th Special Operations Squadron Night Bombers, was flying dive bombing missions over the Ho Chi Minh trail in an effort to interdict human and vehicle traffic. The typical tactic for these missions flown in an A-26A aircraft, was to drop a line of flares over the target, then dive in a circling turn to drop either bombs, bomblets, napalm, or strafe targets with the fifty caliber guns (8). In Col Simons words, "After several night sorties, it appeared obvious that if I could see the very small targets 30 seconds to a minute before my arrival, I could attack more effectively with a pre-look at the target. With a small monitor in the cockpit and a zoom sensor hanging on its own chute in the flare train, the Special Operations Squadron of A-26As could have charged the trail more accurately and enhanced their own survivability by searching with a pre-look for AAA." Providing the pilot with a simple, low cost, real-time reconnaissance device was the essence of Col Simons' concept of "optimizing one man in one aircraft." In terms of developing the concept, he thought it particularly important to keep the device simple and avoid what he termed the "avionics trap," (i.e., employment of unnecessary expensive exotic avionics equipment.)

Unfortunately, by the time Col Simons returned to the Aeromedical Research Laboratory (AMRL) at Wright-Patterson AFB in 1969, (then a Lt Col and Branch Chief at AMRL) the research and development climate was "lasers can do anything" and the more exotic the avionics, the better. Nevertheless, Col Simons actively pursued support for this concept within several Air Force organizations, but funding priorities were shifted towards developing the more elaborate solutions to the targeting of weapons. It was during this same time period that Col Simons and a small group of scientists at AMRL were developing and testing another concept that was later fielded by this laboratory in Vietnam, the side-firing AC-47 gunship known as "Puff" (the Magic Dragon). Thus, while the success of one of Col Simons' concepts, "Puff" has become legendary over the years, the progress of his real-time reconnaissance concept has been somewhat stymied until recently.

Technological lags have also contributed to development delays of a low cost Sensor Preview Imagery (SPI) device to transmit real-time reconnaissance information directly to the aircraft. However, with advances in secured data link capabilities and miniaturization of sensor packages, this is no longer the case. Tactically, the successful employments of UAVs by the Israelis over Lebanon and U.S. over Iraq have proven the UAV's advantages. The next logical step is to provide these advantages directly to the aircrews in real-time.

Making Col Simons' idea a viable system requires defining SPI to accomplish mission goals in a cost effective manner. This was accomplished by developing the concept using "synthetic environments" to prototype the system. Hence, the work presented in this report deals with system performance and the critical human-machine interface design issues involved in developing a viable real-time reconnaissance asset for the Air Force.

Three important questions guided this proof of concept project. These deal with: (a) what is gained in terms of mission effectiveness with target pre-looks for different mission scenarios; (b) how to determine the optimum pre-look range for different missions; and (c) how to facilitate a crewmember's information management of real-time reconnaissance data. Thus, these questions guided development of a methodology for initial SPI proof of concept simulation. This methodology is not limited to this particular proof of concept project, but could be used as a method for developing any weapons system concept. The basic tenet in this methodology is to determine final weapons system requirements before building system prototypes that have been guided by a combined set of human performance and mission requirements. The methodology presented here is based on two critical concept development phases.

The first phase in our proof of concept project presents results from what we term our "paper and pencil analyses." That is, the data presented in Phase One are a detailed set of analyses deriving human systems requirements for SPI based on the "ideal observer" or normative models of human visual perception and a perfect weapons system. It is this phase that is most often presented as a proof of concept study.

The second phase to our proof of concept study is what we believe to be the critical "missing link" between paper and pencil analyses and system hardware prototyping. Phase Two of our proof of concept methology is a human-in-the-loop study designed to test the validity of the results from Phase One. That is, do the system requirements derived from "paper and pencil analyses" hold up in simulation with real operators? The point is that problems encountered with a new system during human-in-the-loop simulation studies (laboratory and in-flight) permit revisions to system requirements before hardware prototyping and could eliminate costly redesign. Therefore, Phase Two of this report presents results from our first human-in-the-loop simulation and then suggests recommendations for further follow-up studies as preludes to flight test.

In sum, this report presents results from Armstrong Laboratory's first SPI proof of concept study designed to investigate critical human-machine interface issues involved in developing a viable real-time reconnaissance asset for the Air Force. We have emphasized the need to test results of "paper and pencil" system requirements analyses before actual hardware prototyping. To this end, we suggest using synthetic environments for human-in-the-loop studies to accomplish initial system prototyping. Thus, this report offers a new methodology for developing any weapons system concept incorporating both analytical studies and synthetic environments to define system requirements in a cost effective manner.

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ACKNOWLEDGEMENTS

This report describes the development of a targeting concept for obtaining imagery from an off-board sensor for strategic bombing missions. An image-transmitting sensor platform, Sensor Preview Imagery (SPI), would provide the crew with target prelooks, overlooks and aft looks while the bomber remains at terrain avoidance altitudes. The report was prepared in part by Science Applications International Corporation (SAIC), 1321 Research Park Drive, Dayton, Ohio 45432 under Contract No. F33615-C-87-0531. The work was performed in support of the Crew Systems Integration Branch within the Human Engineering Division of the Crew Systems Directorate (AL/CFHI), Wright Patterson Air Force Base, Ohio.

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EXECUTIVE SUMMARY

PURPOSE

This report documents the results of a three-phase concept development project that employed traditional analytic techniques as well as man-in-the-loop simulation. "Paper and pencil" analyses were conducted followed by a dynamic simulation. The simulation provided sufficient detail for exercising the concept with operational crew members.

The Sensor Preview Imagery (SPI) concept involves the use of an air-launched, autonomous vehicle equipped with off-board sensors designed to support conventional and other strike aircraft operations. The SPI missile is launched to arrive in the target area prior to the attacking aircraft. SPI sends transmissions (i.e., imagery of the target area) back to the aircraft, thereby providing the aircrew with a pre-look to verify target position, status, and defensive countermeasure employment. With this information, the strike aircraft may choose to modify the mission plan for threat avoidance (potentially improving survivability of the strike vehicle), and/or alter weapon delivery programming to enhance weapon lethality. The SPI concept provides aircrews with a self-contained capability for advanced reconnaissance, target acquisition, threat avoidance and bomb damage assessment with increased survivability.

The purpose of the SPI study was to quantify SPI system and mission parameters through "paper and pencil" and simulation analyses. In doing so, an estimate of SPI's mission benefit was quantified.

METHOD

The SPI study entailed the use of analytical and experimental techniques. The analyses started with the development of a railyard attack mission that served as the "forcing function" for all subsequent procedures.

Candidate system parameters were developed analytically taking into account mission requirements, timing, target geometry, and target acquisition

requirements. The results of these analyses served as input into the development of a part-task, part-mission simulation of SPI.

Experienced B-52 radar navigators (RN) participated in a "real time" part-task simulation. An optimum attack plan, based on target location in the railyard, was specified that would result in the desired Fractional Coverage (FC) with the minimum number of sorties. Subjects were given the opportunity to modify the attack plan based on SPI imagery; or execute the planned tactic which did not take real-time target information into account.

Measures evaluated included: (1) percent correct decisions as a function of number of passes and target configuration, (2) average imagery viewing time, (3) average imagery review time, and (4) average confidence ratings. Following the simulation study, subjects were debriefed in order to obtain subjective data.

RESULTS

The SPI study resulted in an initial concept for enhancing mission effectiveness for a notional mission against a fixed target. The empirical results showed that subjects could use SPI to improve their decision process for selection of the optimum attack plan. The optimum attack plan was selected between 53% to 73% of the time, resulting in a substantial reduction in required number of sorties. Therefore, these results suggest that a SPI with sensor resolution, flight parameters, and a man-machine interface similar to that used in this study would serve as a force multiplier. Application of our data to the modeling results for required number of sorties to achieve a desired FC suggest that SPI can decrease the required number of sorties between 36% to 49% based on the subjects' improved accuracy. These results are suggestive and would require additional modeling on empirical data for validation.

The RNs were highly in favor of the SPI concept and their comments are consistent with the empirical results of the simulation. All RNs stated that the SPI mission, simulation, imagery, man-machine interface (i.e., the controls and displays) were adequate for demonstrating the effectiveness of the SPI proof-of-concept demonstration.

Future research studies should include the following: (1) additional part-task, man-in-the-loop simulations using alternative mission/operational parameters, (2) more complete synthetic environments that include real and simulated objects and imagery, (3) crew workload and mission management evaluation to assess improved mission performance and potential reduction in workload exploiting a virtual cockpit environment, and (4) in-flight simulations that utilize canned or prerecorded imagery of an actual mission route.

REPORT CONTENTS

The following is a preview of document contents:

Section 1: Introduction. This section contains a discussion of the background of the SPI program, an introduction to the study goals and objectives, and an overview of the two-phase study approach used for the SPI research effort.

Section 2: Phase I: SPI System Requirements Analysis. This section presents the details of the "paper and pencil" SPI system requirements analyses that were conducted.

Section 3: Phase II: Man-in-the Loop Design Simulation. This section describes the details of the SPI part-task simulation of a B-52 railyard attack mission. Specifically, this section includes the experimental design (i.e., the mission timeline, trial sequence, stimulus population, independent variables, dependent variables, apparatus, test subjects, and procedures).

Section 4: Results. This section presents the results of the performance and subjective data of the Phase II SPI part-task simulation.

Section 5: Summary and Recommendations. This section presents a summary and discussion of the important outcomes of

the study in terms of the original study objectives. In addition, recommendations are made for future research studies.

Appendices. These sections present detailed information and raw data on the following topics: (a) orientation mailer, (b) instructions for SPI experiment, (c) structured debrief questionnaire, and (d) summary of results of the structured debrief questionnaire.

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SECTION 1
INTRODUCTION

PURPOSE

This report documents the results of a two-phase concept development process that employed traditional analytic techniques as well as man-in-the-loop simulation. "Paper and pencil" analyses (i.e., SPI system requirements analyses) were conducted followed by a dynamic simulation. The simulation provided sufficient detail for exercising the concept with operational crew members.

The Sensor Preview Imagery (SPI) concept involves the use of an air-launched, autonomous vehicle equipped with off-board sensors designed to support conventional and other strike aircraft operations. The SPI unmanned aerial vehicle (UAV) is launched to arrive in the target area prior to the attacking aircraft. SPI sends transmissions (i.e., imagery of the target area) back to the aircraft, thereby providing the aircrew with a pre-look to verify target position, status, and defensive countermeasure employment. With this information, the strike aircraft may choose to modify the mission plan for threat avoidance (potentially improving survivability of the strike vehicle), and/or alter weapon delivery programming to enhance weapon lethality. The SPI concept provides aircrews with a self-contained capability for real-time reconnaissance, target acquisition, threat avoidance and bomb damage assessment with increased survivability.

The purpose of the SPI study was to quantify SPI system and mission parameters through "paper and pencil" and simulation analyses. In doing so, an estimate of SPI's mission benefit was quantified.

BACKGROUND

The SPI concept had its origin in 1968 (see preface). The concept was rediscovered again in 1987 when an Armstrong Laboratory (AL) researcher attended the Bomber Tacticians Course at the SAC Tactics School (STS). As part of the course, students were required to solve a specific SAC tactical

targeting problem within a real mission scenario. The idea of an air-launched sensor that would allow the bomber to penetrate and remain low while acquiring the target was generated after participating in this exercise.

The SPI concept as conceived by AL and STS is a near term, low cost, off-board sensor designed to increase target acquisition capability and decrease threat exposure for aircrews involved in conventional or nuclear operations. The missile is carried by an attacking aircraft and launched to arrive in the target area prior to the attacking aircraft. Continuous transmissions sent back to the bomber provide the aircrew with an improved view of the target area and increased target acquisition time, while taking the maximum advantage of low altitude ingress (or depending on the mission, high altitude ingress). Sensors, secured data links, and appropriate platform packages are to be based on current and near-term technology.

The Wright Research and Development Center (WRDC/AART) has provided AL and STS with critical information on existing sensors and secure communication links suitable for SPI. WRDC/AART previously proposed an off-board sensor program named Strategic Off-Board Sensing in their out-year planning (FY92-94) and felt the SPI concept was consistent with their goals. With the support of WRDC/AART, AL, and STS developed the SPI concept and prepared a classified briefing that was presented to HQ SAC on 23 May 1989 by the Director of STS. On 2 July 1989, AL and STS received an HQ SAC/XRH, DOO, XOB coordinated endorsement for future SPI concept development. SAC/XRH noted that the SPI concept had considerable potential for enhancing SAC conventional and nuclear operations and that development of this concept into an operational capability would directly support requirements such as stated in SAC SON 18-82R1, Strategic Conventional Standoff Capability.

The SPI concept illustrated in **Figure 1.1**, consists of an expendable remote vehicle that carries a sensor which is deployed from the strike vehicle, a B-52 for this study; sensor video is telemetered to the strike vehicle providing a visual pre-look of the target area to verify target position, status and defensive countermeasure employment. With this information, the strike vehicle may choose to modify the mission plan for threat avoidance (potentially improving survivability of the strike vehicle), and/or alter weapon delivery programming to

enhance weapon lethality. The figure also identifies many of the engineering issues that were analyzed during Phase I of the study (SPI System Requirements Analyses).

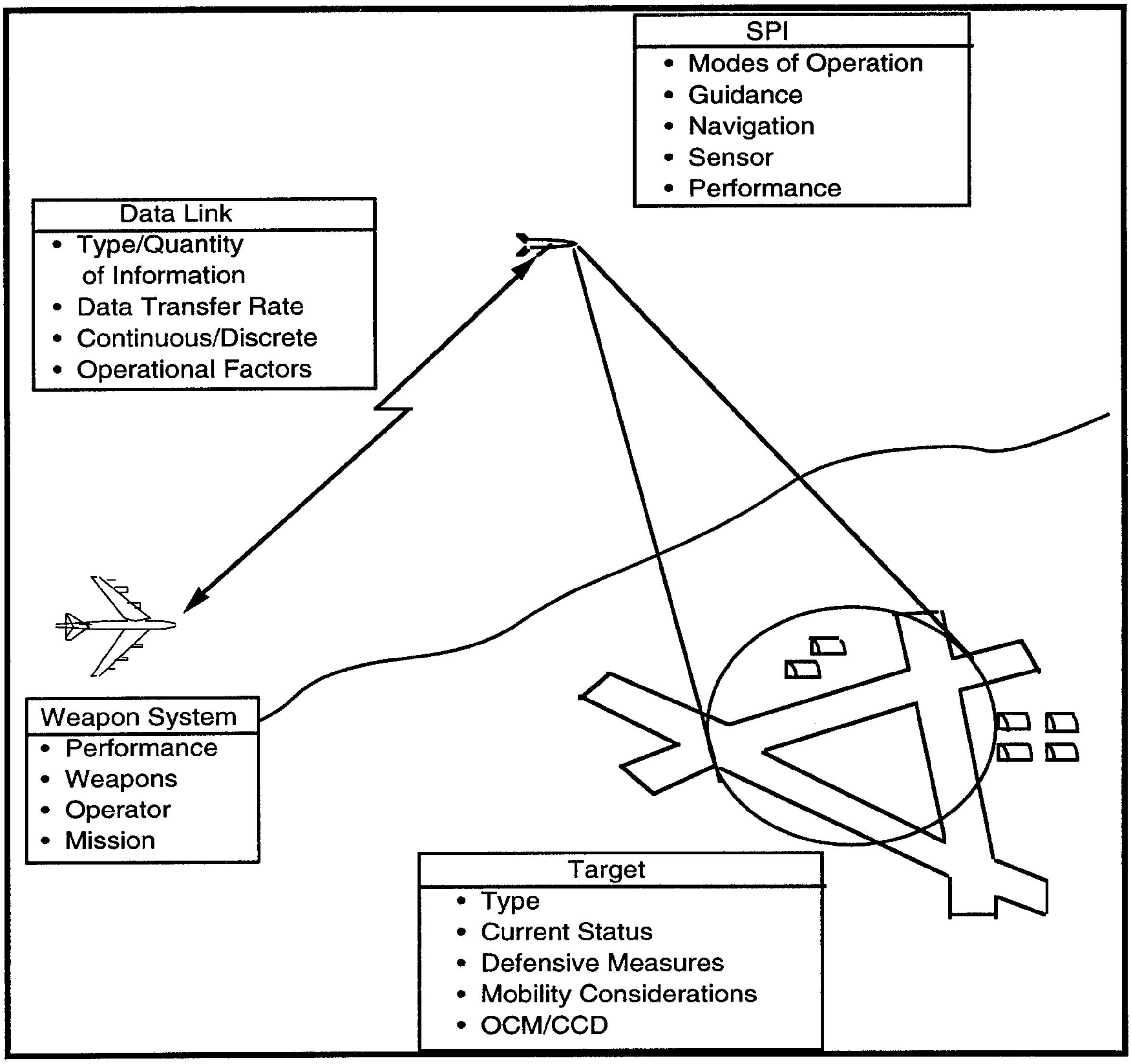


Figure 1.1. SPI Concept and System Requirements Considerations

STUDY GOALS

The objective of this program was to quantify SPI system and mission parameters through "paper and pencil" and simulation analyses. In doing so, an estimate of SPI's mission benefit was quantified. The mission was defined by the SAC Tactics School (SACTS) and was considered representative for a utility evaluation of the SPI concept.

"Paper and pencil" analyses were conducted in order to identify SPI configurations which would best serve SAC's imagery requirements in performing the mission defined by SACTS. Specifically, these Phase I analyses were conducted to: 1) identify imagery requirements and constraints, 2) identify the principle SPI configuration parameters which may be used to meet the imagery requirements, 3) quantify the relationships between parameters, 4) identify a "good" SPI configuration, and finally 5) assess the impact of the SPI configuration parameters on mission planning and execution. The results of these analyses supported the Phase II simulation portion of the study that followed.

Next a closed-loop simulation was conducted with SAC B-52 crewmembers observing target preview imagery for a railyard attack. The Phase II simulation was used to estimate the effectiveness of a SPI with a man in the loop. Measures associated with target acquisition accuracy, and mission replanning were collected during the simulation. The simulation data, in conjunction with weaponeering data from SACTS, were used to estimate the effects of a SPI concept on fractional coverage (FC). The paper and simulation analyses were both used to recommend design parameters for selected SPI configurations.

TWO-PHASE STUDY APPROACH

A two-phase study approach was implemented for the SPI research effort. Throughout each phase close coordination with both SAC Tactics Schools and experienced B-52 crew members was maintained. The following briefly describes the phases and associated objectives. (Please note that further explanation is provided in Sections 2 and 3.)

Phase I: SPI System Requirements Analyses. The purpose of this phase of the study was twofold: to define relevant mission/operational requirements for the SPI concept and to translate those requirements identified into operator-oriented system requirements for SPI. Relevant requirements included: (1) the type of sensor package to use, (2) the link required (i.e., the communication needed between the unmanned vehicle SPI and the bomber),

(3) the selection of the crew positions that could perform the SPI function, and (4) associated crew display and interface designs.

Next, relevant mission/operational requirements were translated into system requirements for SPI. This was intended to be a top-level system requirements analyses, to identify and quantify SPI sensor and vehicle design parameters. The sensor parameters considered were the field of view, depression angle, and snapshot rate (or frame rate); vehicle parameters considered were the altitude, speed and minimum range of the aircraft. Results of these requirements analyses identified a prioritized set of "good" configurations (i.e., parameter combinations) for SPI, based on analytical methods; these results provided a point of departure for the remainder of the effort which included the use of man-in-the-loop simulation. The Phase I analyses are described in detail in Section 2 of this document.

Phase I Objectives:

(1) Define an initial SPI concept to increase mission success for attacks on tactical targets.

(2) Develop a notional tactic for the use of a SPI by B-52 crews.

(3) Identify and quantify SPI sensor and vehicle design parameters

(4) Identify SPI configuration to be used during Phase II simulation.

Phase II: Man-in-the-Loop Design Simulation. The purpose of Phase II was to test the parameters that were identified during Phase I and to verify that a system such as SPI would in fact function properly in an operational setting. The SPI concept and representative land attack mission were implemented in a part-task simulation device. Twelve B-52 experienced crew members served as subjects for the study. A mechanization concept was derived to provide the radar navigator (RN) with an interface similar to the current EVS display. A subset of mission critical data and SPI data were presented on an abbreviated Primary Data Display (PDD) format. The RNs were provided with input devices

to control the SPI data collection, SPI imagery replay, and desired mean point of impact (DMPI) selection.

Phase II Objectives:

(1) Test the derived "parameter combinations" identified for SPI during Phase I.

(2) Estimate the mission benefit of a SPI in terms of probability of target acquisition, increased FC, and impact on required number of sorties to achieve a desired FC.

(3) Develop a preliminary man-machine interface and address human factors issues associated with real-time image interpretation and mission replanning.

The study resulted in an initial SPI concept for enhancing mission effectiveness for a notional mission against a fixed target. The performance data present estimates in terms of measures of effectiveness (MOEs) of the potential benefit of an SPI concept. The RNs comments and suggestions present directions for enhancing or modifying this initial concept. Section 4 of this report describes the details of the concept employed in the part-task simulation and Section 5 presents the results of the analysis of the performance and subjective data.

SECTION 2
PHASE I: SPI SYSTEM REQUIREMENTS ANALYSES

INTRODUCTION

This section of the report describes the "paper and pencil" SPI system requirements analyses that were conducted during Phase I of the study. These analyses were conducted in order to: 1) identify imagery requirements and constraints, 2) identify the principle SPI configuration parameters which may be used to meet the imagery requirements, 3) identify a "good" SPI configuration, and finally 4) assess the impact of the SPI configuration parameters on mission planning and execution. The results of these analyses supported the development of the Phase II part-task simulation.

Table 2.1 presents a summary of the SPI parameters, underlying rationale for these parameters, and the resulting SPI system requirements as determined by the Phase I "paper and pencil" analyses. The remainder of this section contains the supporting documentation for these results. Specifically, this section contains a discussion of SPI imagery requirements, SPI system design parameters, critical mission elements and constraints, static and dynamic analyses performed, and the recommended parameters to be used during Phase II simulation.

IMAGERY REQUIREMENTS

Overview

The primary objective of the SPI imagery is to provide a real-time pre-look of the target area. This pre-look will enable the strike platform an opportunity to: (1) verify target position, status and defensive countermeasure employment, (2) modify mission plan for threat avoidance, and/or (3) reallocate/reprogram weapons to maximize the probability of destruction.

Table 2.1. Phase I SPI System Requirements Summary

SPI Parameters	Rationale	Analyses Based SPI System Requirements
Clear Line of Sight to Target	• Terrain Occulting/Intervisibility • Cloud Free Line of Sight • Atmospheric Visibility Statistics	• SPI Altitude > 1000' AGL • SPI Altitude < 3000' AGL • SPI Slant Range < 4 Statute Miles
Spatial Awareness of Target Area	Identification of DMPIs and Stick Zones	Footprint Dimensions Not Less than 1000' by 3000'
Resolution	• Detect Rail Cars • Recognize ZSU-23/4	• Resolution < 4 Feet/Line • Resolution < 1 Feet/Line
Lead Time	SAC Tactics School Guideline	Imagery Available at Least 2 Minutes Prior to B-52 Arrival Over Target
Sensor	• Field of View • Depression Angle • Frame Rate	• Field of View HFOV = 20.63° VFOV = 15.47° CFOV = 25.79° • Depression Angle = 15.52 ° • Frame Rate (See Table 2.3)
UAV PLATFORM	Imagery Quality and Mission Planning Impacted by UAV Platform Performance (Speed, Altitude, and Range)	• Speed = 415 kts • Altitude = 2500' AGL
DATA LINK	• Sufficient Bandwidth	• Capability to Pass 875 Line Video

This objective imposes a number of requirements on the SPI provided imagery. First, SPI must have a clear Line-Of-Sight (LOS) to the target area. Second, the SPI imagery must provide a "big picture" view of the target area to allow the RN to make targeting decisions. Third, the RN must be able to see actual target elements to some level of detail. Finally, the SPI imagery must be provided with

sufficient lead time to allow the RN to decide how to take advantage of the imagery, and to implement that decision by redesignating and/or reprogramming the weapons computers. The following provides a detailed discussion of each of these imagery requirements.

Clear Line-of-Sight (LOS)

The most obvious factor affecting the probability of a clear Line-of-Sight (LOS) is the potential for terrain masking, as is depicted in **Figure 2.1**. The effect of terrain masking is location and geography dependant, and may sometimes be reduced or eliminated by appropriate mission planning of the SPI route using topographical maps. Rolling terrain presents a more difficult problem than that represented in the figure. An analysis of European Fulda Gap terrain was used to determine the probability of a clear LOS as a function of vehicle altitude and distance.

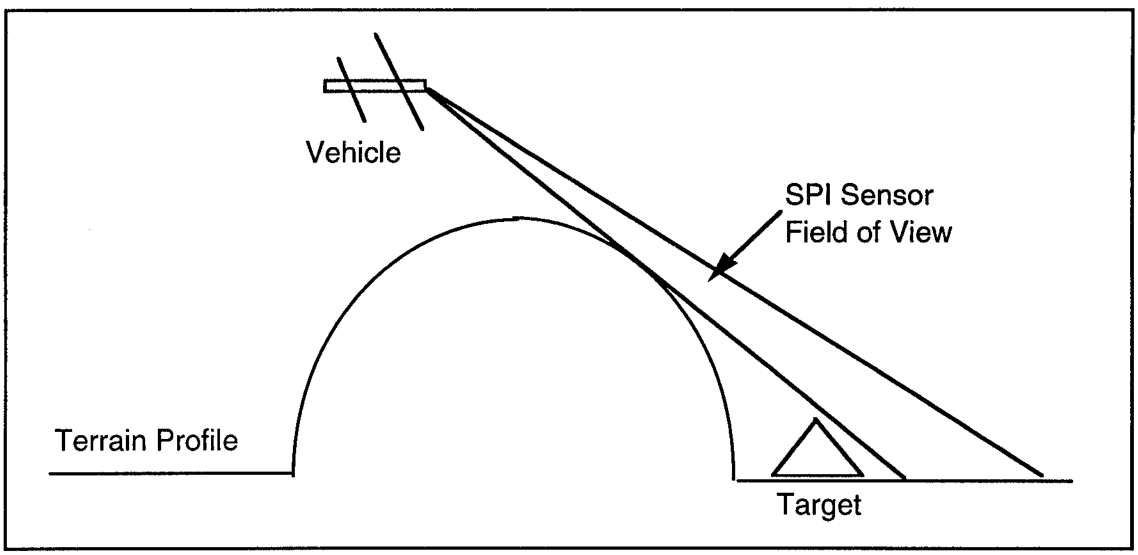


Figure 2.1. Illustration of the effect of terrain profile on target imaging.

An analysis using meteorological data for Kassel, FRG, showed a sharp reduction in the probability of a clear LOS between 1000 and 3000 feet altitude.

Finally, absolute humidity of the atmosphere, the presence of aerosols, smoke, etc. effect the degree to which electromagnetic radiation is attenuated and/or diffused. This effect "washes out" the scene. The attenuation effect varies

greatly with the spectral bandwidth of the sensor. Visibility is a loose measure of these effects in the visible spectrum. In the infrared spectrum, sensor detection capabilities generally follow the same trends as the visibility curves but with generally greater magnitudes. For analysis purpose visibility was assumed to be of the order of 3 statute miles.

Spatial Awareness of Target Area

SPI imagery must provide a sufficiently "big picture" to allow the image interpreter to correlate SPI imagery with the photographs and charts describing the mission in the Crew Mission Folder (CMF). Landmark cues and overall target layout in the imagery must be correlated with the CMF, to provide a reasonableness check and spatial orientation prior to selecting a targeting strategy.

Resolution

SPI imagery must provide sufficient resolution to allow the image interpreter to "see" individual target elements to some criteria. In the rolling stock mission, individual train cars must be detected in order to locate which area contains the highest car density.

For the purpose of analyses, detection, recognition and identification have specific quantitative definitions based on the Johnson criteria (Johnson, 1958). According to this criteria, 50 percent of the subjects detected the presence of something of interest in a video frame when 2 lines of video subtended the critical dimension of the target of interest. Similarly, recognition that a vehicle is a tank, jeep, APC, etc. requires 7 lines of video; identification of a target as a T-62 versus an M-1 tank requires 14 lines of video.

For the purpose of analyses, it is also assumed that SPI imagery will be presented at the RN station in the B-52. The display at this station has an 8 inch diagonal with a 4/3 aspect ratio, and requires 875 line format RS-343 video. This video standard provides 842 lines of active display, and must be considered during the configuration analysis to verify the imagery will have adequate resolution based on the criteria selected for the particular mission.

Lead Time

Lead time is one of the most important parameters to be provided by the SPI concept. A B-52 flying at terrain following altitudes has very little time between spotting the target and releasing ordinance. The principal purpose of SPI is to provide sufficient lead time to allow the interpreter to redesignate the steerpoint around which weapons release will occur, or reprogram weapons to maximize weapon lethality.

Based on SAC Tactics guidelines, crewmembers require a lead time of 2 minutes prior to B-52 arrival over the target area. This allows the crewmembers to review SPI imagery and modify the mission plan and/or alter weapon delivery programming.

SPI SYSTEM DESIGN PARAMETERS

The following describes the primary SPI system parameters that impact imagery requirements. These parameters are organized by the four SPI systems (i.e., the sensor, the Unmanned Aerial Vehicle (UAV) platform, the datalink, and the strike platform (B-52)).

Sensor Parameters

Based on preliminary concept development analyses and operational goals of a SPI system, it was determined that the SPI sensor must be inexpensive, since the UAV and sensor are expendable. A passive framing device has been assumed for these analyses, though the sensor might be an imaging radar or a line scanning device. Because the sensor must be sensitive to nighttime electromagnetic radiation, either an image intensification device such as Low-Light Level TV (LLLTV) or Forward Looking Infra-Red (FLIR) was recommended.

Two sensor parameters dominate the imagery spatial relationships for static frames. These are the sensor field of view (FOV) and the sensor depression angle. FOV, which consists of vertical and horizontal components (VFOV and

HFOV respectively) defines the total included angle of the video imagery in each direction. Depression angle is the angle from the local horizontal to the line of sight of the optical center of the FOV. Some sensors have a zoom feature, which dynamically changes FOV in a continuous fashion, producing increased magnification for reductions in FOV. Some sensors have two discrete FOVs, wide and narrow, and may switch between them essentially instantaneously. In addition, sensors may be gimbaled to control depression angle, azimuth look angle, or both.

In summary, the primary configuration parameters for the sensor are its controllability, field of view, depression angle and frame rate. These are the parameters which must be considered in defining the concept for the railyard mission. Secondary issues, which are technology dependent, include sensor size, weight and cost.

UAV Platform Parameters

The UAV platform must be inexpensive and certifiable for B-52 carriage. It must have sufficient payload volumetric and weight capacity to carry the sensor and datalink systems. It must also have sufficient range and endurance to fly the desired route to the target area. It must be able to fly at an altitude consistent with the cloud free line of sight statistics cited earlier. Finally, it must fly at some speed to provide target imagery with adequate lead time.

The impact of vehicle performance (speed, altitude and range) on imagery quality and mission planning can be significant. The ratio of speed/altitude dominates the dynamic imagery relationships for imagery frame rate and overlap (or ground track coverage). Altitude also drives the static, single-frame ground track footprint size, which is critical to achieving spatial awareness. Speed and range combine to drive the placement of the SPI launch point relative to the target; mission geometry, combined with these parameters define the amount of lead time which can be achieved.

The final UAV system parameter(s) may be termed controllable. The UAV platform may be totally self-contained and autonomous, or may rely on the strike platform for navigation, guidance and control either partially or completely. The

benefit of an autonomous SPI is that it requires no emissions from the strike vehicle; the primary disadvantage is that the system must be preprogrammed prior to launch, and has no flexibility after launch. The benefit of having most of the guidance and navigation on the strike vehicle is the cost of the expended UAV; the disadvantage of this approach is the strike vehicle must maintain an uplink with the UAV (i.e., the strike vehicle must be emitting to tell the UAV where to go).

In summary, the primary UAV system configuration parameters which must be considered (to some level) are the altitude, speed, range and controllability. Secondary issues include the payload capacity, endurance and certifiability (for B-52 carriage).

Data Link Parameters

The datalink provides video downlink from the SPI vehicle to the strike vehicle. The datalink must have sufficient bandwidth to pass 875 line video at some frame rate. For relatively slow frame rates, it may be possible to incorporate burst transmission, to minimize the probability of intercept, encryption, to minimize the potential for hostile intelligence monitoring of the video, and/or jamming countermeasures, to maximize the probability correctly receiving and decoding of the video by the strike vehicle.

Datalinks generally require an unobstructed line-of-sight to the receiver. Given that the strike vehicle is flying at terrain following altitudes, terrain masking of the SPI/strike line-of-sight is conceivable, especially at long range.

B-52 Strike Platform Parameters

A variety of issues must be considered in the system design relative to the strike platform. First, it must have sufficient capacity to house SPI related avionics, including the datalink receiver/transmitter, display interface avionics, as well as any additional avionics associated with SPI control.

Human factors issues associated with SPI also present significant design requirements. First, SPI imagery must be interpretable; this may require

buffering of the SPI imagery, especially for complex imagery or for a high speed vehicle. Secondly, for controllable SPI concepts, the man-machine interface issues must be considered to provide an interface which does not impose excessive workload.

CRITICAL MISSION ELEMENTS

In order to evaluate the SPI concept, a representative railyard attack mission was developed. The objective of the mission is to destroy stationary rolling stock, primarily boxcars, flatbed cars and locomotives. The mission is preplanned using map, satellite images, and/or other photo-reconnaissance imagery, and any other intelligence data available; the mission plan contains the route information, photographs of the target area, and a number of preplanned targeting points known as DMPI's, for Desired Mean Point of Impact. Each DMPI has a "stick" associated with it; the stick indicates the anticipated ground area which will be covered by the bomb pattern. Three B-52 aircraft fly the mission in close trail, each aircraft with a predesignated DMPI in the target area.

SPI can enhance the probability of destruction by providing imagery which allows the image interpreter to identify the "best" DMPI(s) to target. Hence, SPI imagery must provide the "big picture", to allow the interpreter to identify where the DMPI sticks lie on the imagery, with adequate resolution to detect individual rail cars.

Secondary objectives in configuring the SPI vehicle is to provide sufficient resolution to detect threats in and around the target area, and to provide bomb damage assessment. The threat selected for the resolution analysis is a ZSU-23/4 anti-aircraft artillery. To provide bomb damage assessment, the vehicle must loiter in the target area until the last strike vehicle has egressed, and smoke has cleared sufficiently to provide reasonable imagery.

The primary mission constraint is to detect individual boxcars while providing adequate spatial awareness to identify individual DMPI regions. For the purposes of the resolution analysis, a representative rail car was selected, with

nominal dimensions of 40 ft. length by 8 ft. width by 10 ft. height. The critical dimension of this car is 8 ft.

STATIC/DYNAMIC FRAME ANALYSES

Two types of frame analyses were conducted as part of the Phase I system requirements analyses. A static frame analysis was performed in order to identify SPI system parameters which affect the properties of a single, static snapshot of SPI imagery. Next a dynamic imagery analysis was performed in order to determine the effect of system parameters on ground track coverage. The following describes each of these analyses.

Static Frame Analysis

The purpose of the static frame analysis was to specify those SPI parameters that impact the properties of a single, static snapshot of SPI imagery. Once these parameters were identified, configurations which meet the system requirements as defined in **Table 2.1** were specified.

The primary parameters of interest in the static frame analysis are the dimensions of the snapshot footprint, and the resolution of the snapshot. The footprint refers to the dimensions of the patch of ground appearing in the image, and determines whether the entire target area can be seen; this is crucial for identifying the preplanned DMPI's and stick zones. Image resolution refers to the size of the smallest item which can be seen in the image, and must be consistent with the size of individual rail cars and threats.

The primary SPI design parameters which affect these imagery characteristics are the sensors' field of view, depression angle, and vehicle altitude. A representative case defining the image geometry is presented in **Figure 2.2**. In **Figure 2.3**, an overview of the footprint is presented. Note that the image ground footprint is trapezoidal; while sensors have a circular lens, which produce an elipsoidal ground footprint, the image is presented on a rectangular screen by truncating the elipsoid. A measure of the resolution of the imagery is presented in **Figure 2.4**; this plot shows the obvious trend that the closer the object is to the sensor, the better the resolution.

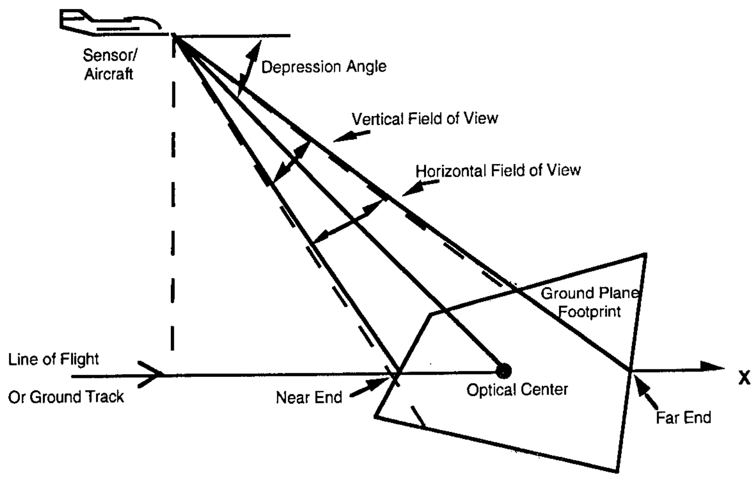


Figure 2.2. Single snapshot geometry parameters.

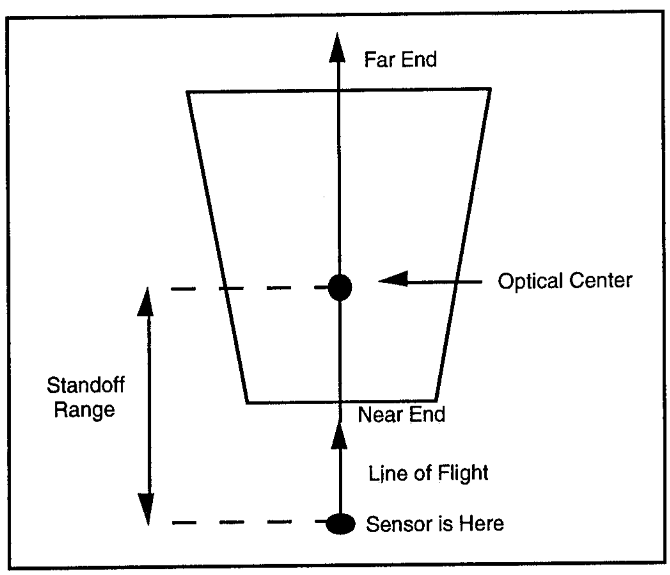


Figure 2.3. Single snapshot geometry footprint overview.

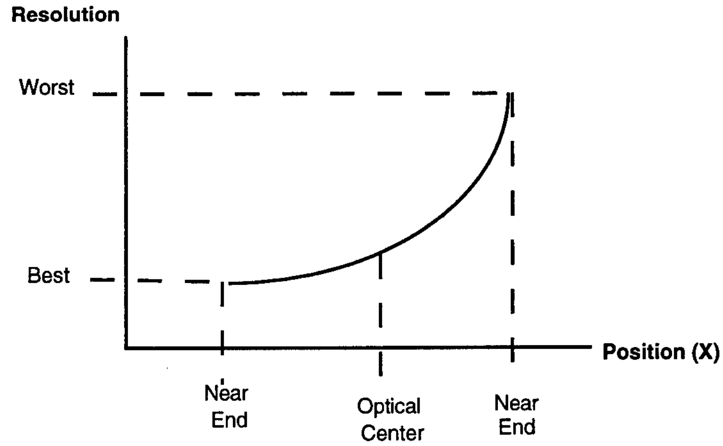


Figure 2.4. Single snapshot geometry, resolution versus position in footprint.

A sensitivity analysis was performed, examining the effects of changes in sensor field of view, depression angle, and altitude on image footprint area and image resolution. This was treated as a feasibility study, to determine if configurations existed which met all of the requirements specified in **Table 2.1**, with the added requirement that SPI could image the entire target area from any ingress bearing. This requirement was imposed to add flexibility to the mission planning process.

Table 2.2 presents a summary of configurations deemed suitable for further analysis. No configurations were found which could image the entire target area for all ingress bearings, while providing the resolution required to recognize the threat. For example, set 1 and 2 configurations provide ingress bearing flexibility, but threat recognition may not be possible. In contrast, set 3 and 4 configurations provide threat resolution, but ingress bearings are restricted. Sets 1 and 3 provide 6000 ft. standoff range (approximately 1 nautical mile), while sets 2 and 4 provide 9000 ft. standoff range (approximately 1.5 nautical mile).

Table 2.2. SPI Configurations Deemed Suitable.

Set	Config	Altitude (Feet)	Depression Angle (degree)	Horizontal FOV (Degree)	Vertical FOV (Degree)	Circular FOV (Degree)	Probability of a Cloud Free Line of Sight (Percent)	Ground Track Range to the Near End (Feet)	Width at the Near End (Feet)	Ground Track Range to the Optical Center (Feet)	Width at the Optical Center (Feet)	Ground Track Range to the Far End (Feet)	Width at the Far End (Feet)
1	a	2000	18.43	30.09	22.57	37.61	67.00	3503.70	2168.81	6000.00	3400.00	15941.03	8636.88
	b	2500	22.62	29.31	21.99	36.64	56.00	3761.03	2285.41	6000.00	3400.00	12149.66	6488.35
	c	3000	26.57	28.44	21.33	35.55	46.00	3947.99	2436.16	6000.00	3400.00	10531.85	5550.32
2	a	2000	12.53	20.89	15.67	26.12	66.00	5388.08	2084.36	9000.00	3400.00	24361.85	9014.43
	b	2500	15.52	20.63	15.47	25.79	55.00	5816.05	2267.07	9000.00	3400.00	18278.91	6715.38
	c	3000	18.43	20.32	15.24	25.40	45.00	6136.10	2409.51	9000.00	3400.00	15703.54	5729.80
3	a	1500	14.04	12.91	9.69	16.14	78.00	4386.31	1042.71	6000.00	1400.00	9268.29	2125.33
	b	2000	18.43	12.63	9.47	15.79	67.00	4672.70	1118.28	6000.00	1400.00	8205.50	1869.54
	c	2500	22.62	12.29	9.22	15.37	56.00	4858.25	1170.04	6000.00	1400.00	7689.69	1741.57
	d	3000	26.57	11.91	8.94	14.89	46.00	4986.33	1207.91	6000.00	1400.00	7389.18	1664.37
4	a	1500	9.46	8.77	6.58	10.97	78.00	6627.62	1039.60	9000.00	1400.00	13870.89	2140.74
	b	2000	12.53	8.68	6.51	10.85	67.00	7074.81	1113.22	9000.00	1400.00	122250.28	1884.85
	c	2500	15.52	8.57	6.43	10.71	56.00	7369.65	1163.13	9000.00	1400.00	11456.62	1757.53
	d	3000	18.43	8.44	6.33	10.55	46.00	7577.15	1199.38	9000.00	1400.00	10988.80	1681.00

The configurations identified in **Table 2.2** are considered starting points, and are further refined during the remaining analysis described below.

Dynamic Imagery Analysis

The dynamic imagery analysis extends the results of the static frame analysis to multiple frames which are sequenced in time. The primary concern in this analysis is to determine the effect of system parameters on ground track coverage. Ground track coverage is illustrated in **Figures 2.5** and **2.6**. In **Figure 2.5**, successive frames of imagery do not provide adequate coverage, i.e. some of the ground track is lost or not imaged. In **Figure 2.6**, successive frames of imagery overlap, and ground track coverage is complete.

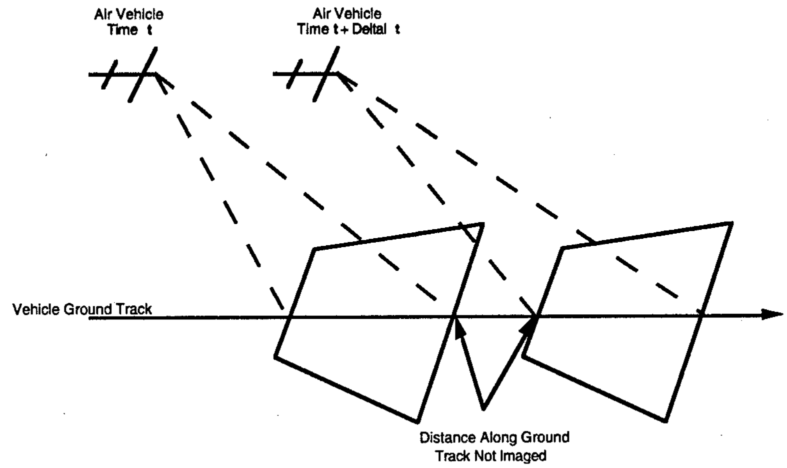


Figure 2.5. Example of sequential frames that do not provide complete coverage of the target area.

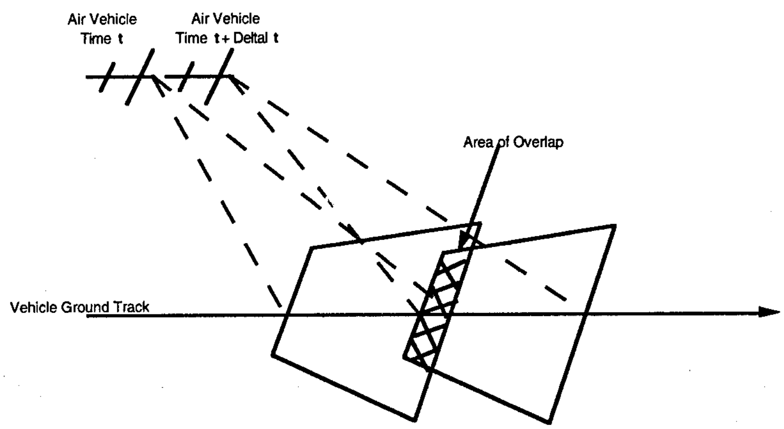


Figure 2.6. Example of sequential frames that provide complete coverage of the target area.

Ground track coverage is quantified using the percentage overlap between successive frames. A positive overlap indicates the level of redundancy between successive frames. Negative overlap indicates the amount of the ground track which is being lost. Overlap can also be directly related to the number of frames that will contain a particular item of interest which is along the ground track, as is depicted in **Figure 2.7**. For example, 50 percent overlap guarantees that a particular object will be observed in 2 successive frames, while 80 percent overlap guarantees that an object will be observed in 5 successive frames.

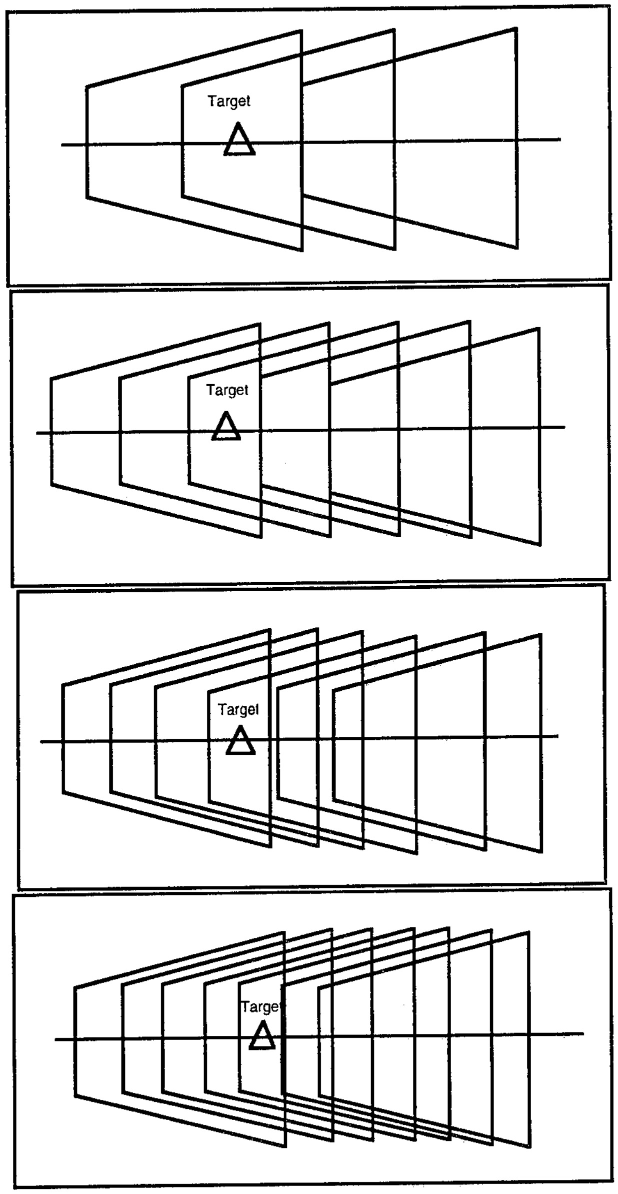


Figure 2.7. Examples of 50%, 66.66%, 75% and 80% overlap which results in two, three, four and five frames containing target, respectively.

Overlap, frame rate, vehicle velocity and footprint dimensions are intimately related. The system designer may specify any 3 of these parameters; the fourth is defined as a result. During this analysis, we chose to set a goal for the amount of overlap, and establish the impact of vehicle velocity on imagery frame rate for each of the configurations defined in **Table 2.2**. The primary reason for this approach is the degradation in resolution with distance from the sensor; for some configurations, resolution changes by a factor of 10 between the near end of the footprint and the far end, placing the goal of detecting rail cars in jeopardy. Consequently, for these configurations, overlap must be set to

guarantee that the target of interest will appear in the near portion of the footprint, where resolution is highest, by specifying an appropriate overlap.

Results of this analysis are presented in **Tables 2.3** and **2.4**. The tables present the effect of vehicle velocity and overlap on the time interval between frames, which is the reciprocal of frame rate. This time interval defines the amount of time the RN has to interpret each frame. **Table 2.3** considers the minimum overlap required for each configuration to meet the resolution requirements; **Table 2.4** shows the effect of specifying an 80 percent overlap.

The results show that for slow SPI velocities, and small depression angles, the time interval is large, and the RN may have sufficient time to evaluate each frame without recording and/or buffering the imagery. But for fast SPI velocities, the time interval is short, as small as 0.5 seconds between frames; for these configurations, the RN will probably not be able to interpret the imagery without providing a buffering mechanism.

Table 2.3. Time Interval Between Frames for Each Configuration -- Overlap Set for Required Resolution.

Configuration	Overlap (Percent)	Time Interval Between Snapshots (seconds)					
		SPI Velocity (Knots)					
		350	400	450	500	550	600
1a	80.00	4.21	3.68	3.28	2.95	2.68	2.46
1b	75.00	3.55	3.11	2.76	2.49	2.26	2.07
1c	66.66	3.72	3.25	2.89	2.60	2.36	2.17
2a	80.00	6.42	5.62	5.00	4.50	4.09	3.75
2b	80.00	4.22	3.69	3.28	2.95	2.69	2.46
2c	75.00	4.05	3.54	3.15	2.83	2.58	2.36
3a	75.00	2.07	1.81	1.61	1.45	1.31	1.21
3b	66.66	1.99	1.74	1.55	1.40	1.27	1.16
3c	66.66	1.60	1.40	1.24	1.12	1.02	0.93
3d	66.66	1.36	1.19	1.05	0.95	0.86	0.79
4a	75.00	3.07	2.68	2.38	2.15	1.95	1.79
4b	75.00	2.19	1.92	1.70	1.53	1.39	1.28
4c	66.66	2.31	2.02	1.79	1.61	1.47	1.35
4d	66.66	1.93	1.68	1.50	1.35	1.23	1.12

Table 2.4. Time Interval Between Frames for Each Configuration -- Overlap Fixed at 80%.

Configuration	Overlap (Percent)	Time Interval Between Snapshots (seconds)					
		SPI Velocity (Knots)					
		350	400	450	500	550	600
1a	80.00	4.21	3.68	3.28	2.95	2.68	2.46
1b	80.00	2.84	2.49	2.21	1.99	1.81	1.66
1c	80.00	2.23	1.95	1.73	1.56	1.42	1.30
2a	80.00	6.42	5.62	5.00	4.50	4.09	3.75
2b	80.00	4.22	3.69	3.28	2.95	2.69	2.46
2c	80.00	3.24	2.83	2.52	2.27	2.06	1.89
3a	80.00	1.65	1.45	1.29	1.16	1.05	0.96
3b	80.00	1.20	1.05	0.93	0.84	0.76	0.70
3c	80.00	0.96	0.84	0.75	0.67	0.61	0.56
4a	80.00	2.45	2.15	1.91	1.72	1.56	1.43
4b	80.00	1.75	1.53	1.36	1.23	1.12	1.02
4c	80.00	1.38	1.21	1.08	0.97	0.88	0.81
4d	80.00	1.16	1.01	0.90	0.81	0.74	0.67

Mission Geometry Analysis

The dynamic imagery requirements analysis considers the effect of system configuration from the standpoint of imagery quality; an independent analysis is required to consider the operational effects of SPI capabilities and mission geometry on the imagery lead time. Lead time is a fundamental SPI system requirement. In order to provide any utility, SPI must present imagery to the RN with sufficient lead time to allow the RN to evaluate the imagery, decide how to take advantage of it, and act on that decision. Lead time is strongly dependant on the range and speed the SPI must fly, as compared with the range and speed the B-52 must fly. SAC Tactics School has indicated that 2 minutes lead time should provide adequate time to make the decision and reprogram the B-52 OAS to fly the new course.

The crucial phase of the mission, with respect to these SPI system requirements, is the time interval between the launch of the SPI, and the B-52 arrival over the target. During this interval, SPI must fly from the launch point to the point where imagery of the target is available to the RN, with 2 minutes to

spare. If a constant B-52 speed is assumed, this time interval is only affected by the range the B-52 will fly during the ingress from the launch point to the target. Further, if the SPI flies a straight line route from the launch point to the target, a simple relationship exists between B-52 range, SPI range (from launch point to target), and SPI speed. This relationship is plotted in **Figure 2.8** for three realistic SPI speeds. As SPI speed is increased, the range that both the B-52 and SPI must fly can be reduced, while still achieving a given imagery lead time.

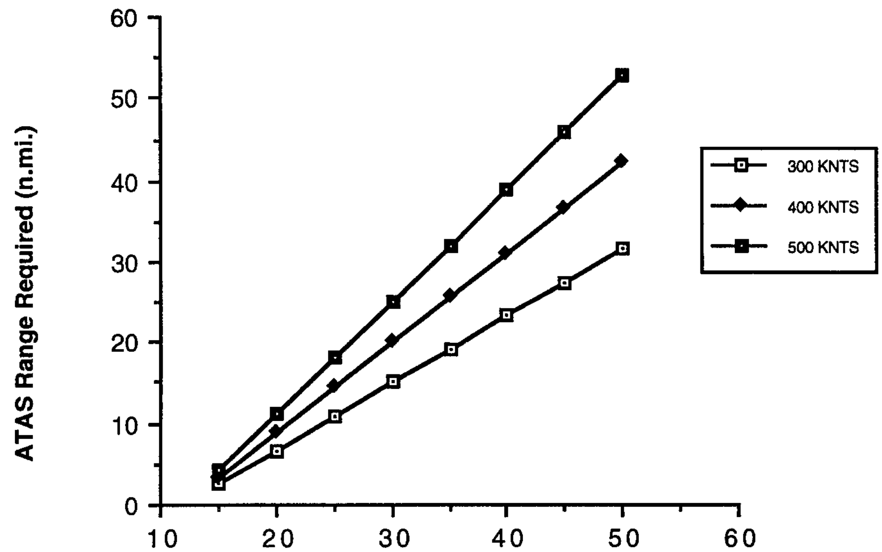


Figure 2.8. SPI Range Required versus B-52 Range to Achieve an Imagery Lead Time of Two Minutes.

Comparing the absolute ranges in **Figure 2.8** can be misleading. The ratio of the B-52 range to the SPI range is more meaningful, and is plotted in **Figure 2.9**. A large ratio indicates the B-52 must fly much longer distances than the SPI vehicle; the B-52 must either loiter while the SPI flies to the target, or the B-52 must take a circuitous route to arrive at the target. Either way, the B-52 is exposed to threats in and around the target area while waiting for the SPI imagery. A unity range ratio indicates the B-52 may fly the same course as the SPI vehicle; this is an optimal solution to minimize B-52 exposure time, but there are tactical considerations which may affect the truly optimal range ratio.

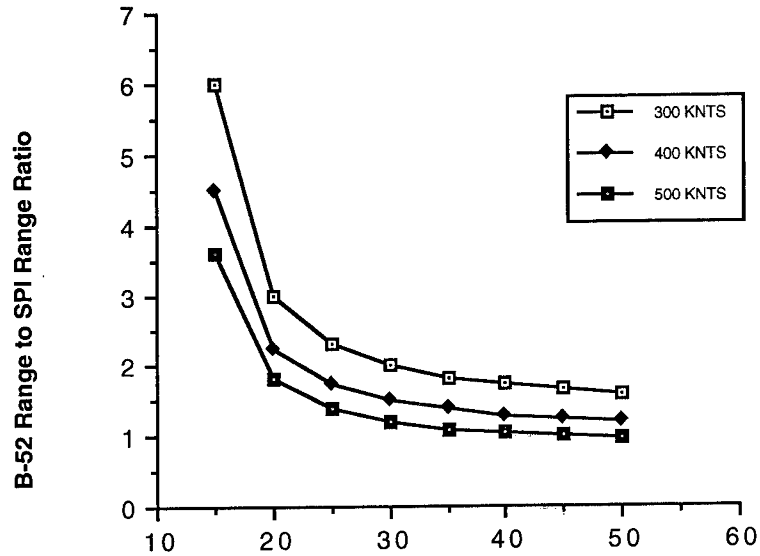


Figure 2.9. SPI to B-52 Range Ratio to Achieve Imagery Lead Time of Two Minutes.

Results of this analysis can be interpreted in multiple ways. The SPI system designer may use these results to specify the minimum acceptable range for SPI, given a vehicle with speed limits. Or, given current tactics, an allowable locus of SPI range and speed combinations can be determined. For instance, if the B-52 will fly the same route as the SPI vehicle, the range ratio is unity; one of the points on the allowable locus requires an SPI speed of 500 knots and minimum range of about 40 nautical miles.

Finally, the tactician can use these results to determine allowable mission geometries, given known SPI speed and range capabilities. Such a plot of allowable mission geometries for various range ratios is presented in **Figure 2.10**; this plot shows where the turn point (for a two-leg ingress route) must be placed to achieve the allowable lead time.

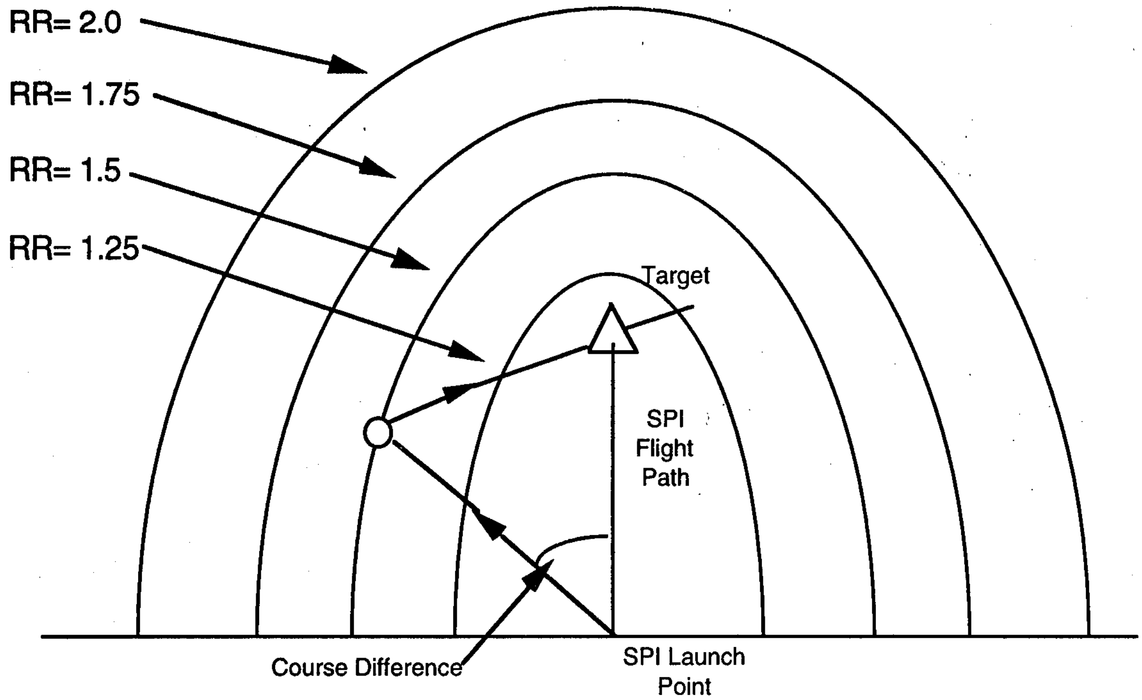


Figure 2.10. Allowable B-52 Waypoint Positions for Various Range Ratios (RR).

PHASE I ANALYSIS SUMMARY AND CONCLUSIONS

The purpose of the Phase I System Requirements Analyses was to define relevant mission/operational requirements for SPI and translate those requirements into SPI system requirements. The Phase I analyses resulted in the identification of SPI imagery requirements/constraints and SPI configuration parameters which could then be used as the basis of the Phase II man-in-the-loop simulation. As identified in **Table 2.1,** ranges for SPI parameters such as altitude, slant range, footprint dimensions, rail car size, lead time, field of view, depression angle, and speed were specified based on the Phase I analyses.

Results of these analyses present a number of design issues which must be considered during SPI system design. The static imagery analysis shows that no single, fixed geometry configuration can meet all of the system requirements; either requirements must be relaxed, or a variable configuration (perhaps multiple field of view) is required. The dynamic imagery analysis shows that SPI configuration and vehicle velocity dramatically impact the rate at which frames must be taken. Yet mission planning considerations indicate high speed is desirable from the standpoint of minimizing SPI range and/or B-52 loiter time.

The system designer must also consider the ability of the RN to interpret the imagery. From an imagery presentation standpoint, the principle issue is the maximum rate at which frames may be presented, yet still be of value. Image buffering may be required to provide the RN adequate time to interpret the imagery; if so, the type of buffering will have an impact on system size, weight and cost. For instance, providing a simple freeze frame capability without actually recording the imagery, may be adequate in providing additional evaluation time, and be very cost effective.

SIMULATION PARAMETER SELECTION

The results of the Phase I Requirements Analyses identified a prioritized set of acceptable SPI system parameters that could then serve as the basis for the Phase II man-in-the-loop simulation. **The SPI parameters deemed most suitable to use as a starting point for the simulation are contained in Set 2, Configuration B as identified in Table 2.2.** This configuration specifies values for altitude (2500 feet), depression angle (15.52 degrees), and field of view parameters (HFOV=20.63, VFOV=15.47, and CFOV=25.79). Set 2, Configuration B parameters were selected because of the following reasons: (1) they provided maximum coverage of the railyard, (2) they provided for an adequate stand-off range, and (3) from an operational perspective, they were the most immune to countermeasures.

The General Electric CompuScene IV (C-IV) was selected for use during the Phase II simulation. The C-IV is a computer image generator that provides a full-mission environment for visual simulations. The C-IV has the capability to realistically display databases mapped directly from the Defense Mapping Agency (DMA). The C-IV also allows for entry of digitized imagery into the database.

Although the C-IV would have allowed programmers to model a railyard for inclusion in the Phase II simulation, due to time and cost constraints, it was decided that an actual photo of a representative railyard would be used. This 2-D representation of the railyard was obtained at a specified altitude, depression angle, and field of view. The railyard representation was digitized

by GE and provided to AL in the form of a bit map file. This file was then integrated into the C-IV terrain database. Next the railyard representation was integrated into the database terrain representation by modifying the surrounding cultural features and terrain texture to enhance visual blending of the railyard complex. Finally, the railyard was populated with 3-D railcar targets.

Simulation runs were conducted and taped onto a super VHS format using the recommended parameters from the Phase I analyses. Because the railcar target complexes were 3-D objects displayed within the context of a 2-D representation, certain simulation perspectives provided unrealistic target cueing. Therefore, certain recommended parameters were modified. For example, once the depression angle was modified from 15.52 degrees to 80 degrees, the railcars appeared to be part of the railyard rather than separate entities. Field of view values also required modifications.

Table 2.5 presents a summary of the SPI parameters and resulting SPI system requirements as determined by the Phase I analyses, and the actual parameters used during the Phase II man-in-the loop simulation.

Table 2.5. Phase I Parameters Summary

SPI Parameters	Phase I Analyses Based SPI System Requirements	Parameters Used During Phase II SPI Simulation
Clear Line of Sight to Target	• SPI Altitude > 1000' AGL • SPI Altitude < 3000' AGL • SPI Slant Range < 4 Statute Miles	• SPI Altitude = 2500' AGL • SPI Slant Range = 1.5 Statute Miles
Spatial Awareness of Target Area	Footprint Dimensions Not Less than 1000' by 3000'	Footprint Dimensions = 1600' by 3900'
Resolution	• Railcar < 4 Feet/Line • ZSU-23/4 < 1 Feet/Line	• Railcar = 4 Feet/Line
Lead Time	Imagery Must be Available at Least 2 Minutes Prior to B-52 Arrival Over Target	2 Minute Trials Containing 30-45 Seconds of Continuous Imagery.
Sensor	• Field of View HFOV = 20.63 Degrees VFOV = 15.47 Degrees CFOV = 25.79 Degrees • Depression Angle = 15.52 Degrees • Frame Rate (See Table 2.3)	• Field of View HFOV = 37 Degrees VFOV = 40 Degrees • Depression Angle = 80 Degrees • Frame Rate = Continuous Imagery
UAV PLATFORM	• Altitude = 2500' AGL • Speed = > 350 kts • Speed = < 600 kts • Sufficient Range and Endurance to Fly Desired Route	• Altitude = 2500' AGL • Speed = 415 kts

SECTION 3
PHASE II: MAN-IN-THE-LOOP DESIGN SIMULATION

INTRODUCTION

This section of the report describes the second phase of the SPI concept study; the man-in-the-loop design simulation. The SPI parameter configuration derived from the system requirements analyses (as described in Section 2) was instrumented as a part-task/part-mission simulation of a B-52 railyard attack mission. This man-in-the-loop simulation study was conducted in order to: (1) estimate the mission benefit that would result from the employment of a SPI; (2) define operationally relevant performance measures; (3) identify and evaluate human factors issues; and (4) obtain subjective input.

Measures of effectiveness (MOEs) in terms of Fractional Coverage (FC) and Number of Required Sorties (NRS) were identified for the target area of interest. In cooperation with the SAC Tactics School, NRS values were determined given a desired FC. The mission objective was to destroy rolling stock. These values were defined under both the assumption of no SPI (current tactic) and a SPI capability.

The above measures (i.e., weaponeering data) were derived analytically using a set of software provided by SAC Tactics School. For the condition in which a SPI capability was assumed, the software accessed locations of the targets in the railyard. That is, information was provided in terms of which of the DMPI areas contained targets and which did not. This assumes a perfect SPI and perfect decision making on the part of the RN.

The results of this study provide data on radar navigator (RN) performance that can be used to estimate the impact of SPI on such measures as NRS. Estimates for NRS are provided that include the impact of the RN's real-time image interpretation and decision making performance.

SIMULATION PLAN

This section describes the mission timeline, trial sequence, and stimulus population. In addition, the experimental design is presented to include the independent variables, dependent variables, apparatus, test subjects, and procedures.

Mission Timeline

A representative mission (i.e., an attack on a railyard) was developed by the SAC Tactics School to aid in the evaluation of SPI concept. The purpose of the railyard attack mission is to destroy stationary rolling stock (e.g. boxcars, flatbed cars, locomotives). The precise positioning of the rolling stock within the railyard is not known prior to the mission.

Current tactics divide this target into four areas for a bomb run, with the centerpoint of each area called a Desired Mean Point of Impact (DMPI). In this mission, some number of B-52 aircraft fly the mission in close trail, each targeting a single DMPI in the target area.

SPI imagery provides the lead strike aircraft with an advanced look at the target area, allowing lead to select the best DMPI. Best is a relative term; in this case, it is the DMPI with the greatest concentration or density of rail cars. Further, lead may choose to command trail aircraft to target other DMPI's based on SPI imagery, further improving lethality. Conversely, SPI may reduce the number of aircraft required to achieve a given level of damage.

SPI imagery might have other additional uses. Assuming sufficient resolution, SPI imagery might allow the detection of threats along the ingress route and in the target area. In the former, this would require sufficient programmability and navigation/guidance capability to follow a preplanned route with waypoints. Further, with a loitering capability, SPI could be used to perform post-strike bomb damage assessment.

Figure 3.1 presents the mission timeline used to exercise the SPI concept. In the preparation of the SPI mission timeline, several new concepts were developed.

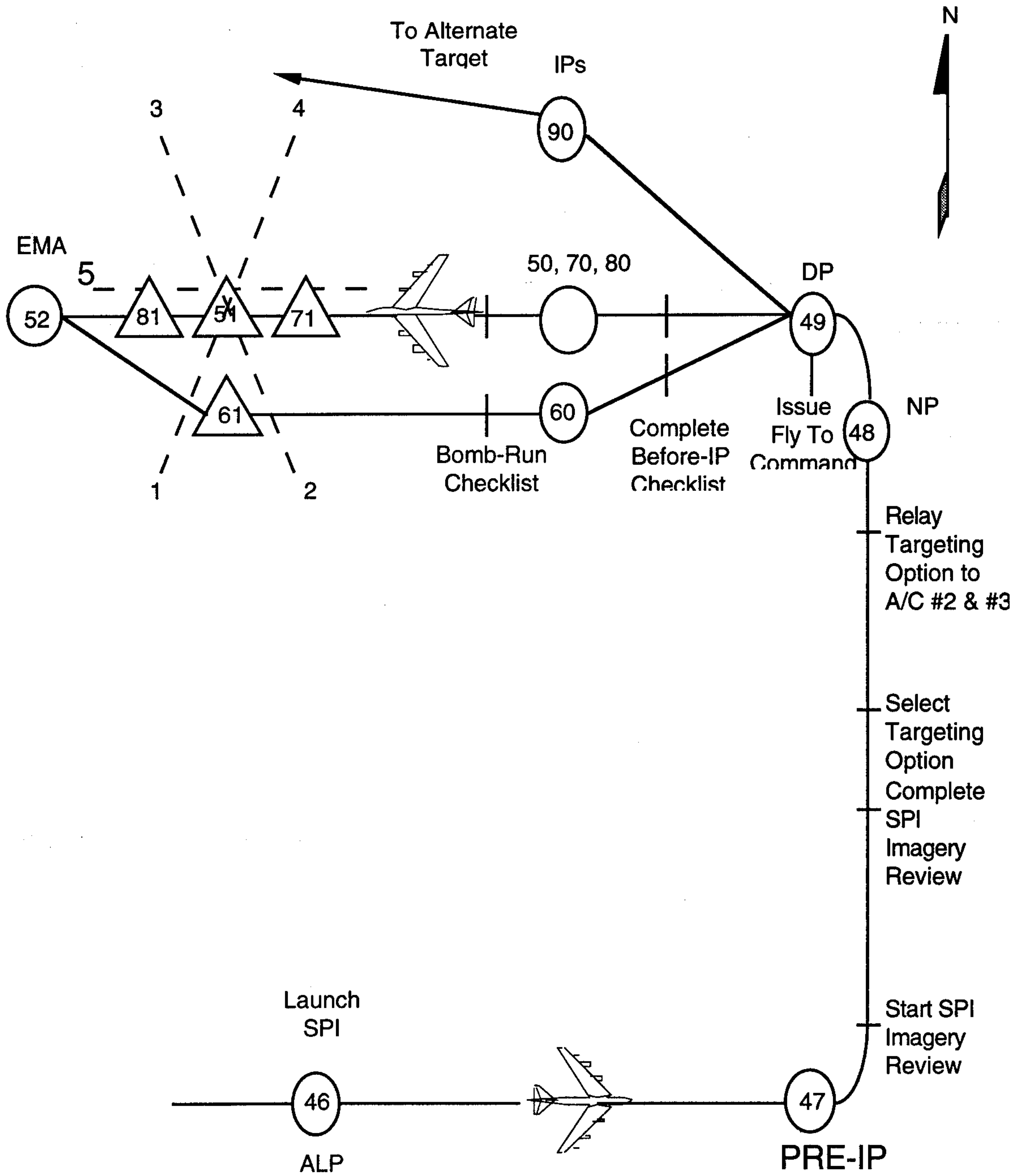


Figure 3.1. SPI mission timeline.

(1) For the purpose of simulation, we assumed that the lead aircraft flying in a three aircraft cell would have primary responsibility for evaluating the SPI imagery and selecting a pre-planned attack.

(2) The mission begins at the Pre-IP and ends at the decision point (DP). The decision point can be defined as that point at which the RN has made his rerouting decision.

(3) In the simulation, the RN begins evaluating the SPI imagery at the Pre-IP. Prior to reaching the DP he must have selected one of eleven available pre-planned attacks. We designed the concept to minimize real-time decision making with respect to mission planning, and to allow the RN to focus on the job of imagery evaluation. An attack plan was selected by matching the target configuration that the RN has perceived with one of eleven possible target configurations. The target configurations are keyed to the decisions that the RN needs to make in terms of: (1) selecting the DMPI for own aircraft, and (2) sending a code to the trail aircraft indicating what attack plan to execute.

As an example, if the RN perceives the major concentration of targets is in DMPI 61, he would select the plan associated with that target distribution. **Figure 3.2** presents a portion of the job aid that was given to the RNs during the simulation. The plan depicted on this job aid indicates that he is to enter "60" in the OAS so that he now targets DMPI 61. Furthermore, it indicates to the pilot the coded message to send to the trail aircraft (i.e., Execute plan "Delta") The trail aircrafts would then select an attack plan based on the coded message received. The concept assumes an integrated attack plan that requires <u>minimal communication</u> between the aircrafts.

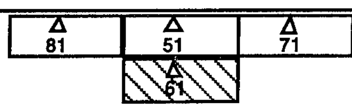
CONFIG.	TARGET CONFIGURATION	RN DECISIONS	PLAN	LEAD AIRCRAFT ENTRY
4		• concentrated in DMPI 61 • ALTERNATE PLAN	Execute plan "Delta"	FLYTO 60 <ENTER>

Figure 3.2. Portion of job aid containing target configurations.

Trial Sequence

As previously discussed, the mission provided by SAC was modified to incorporate the capability of executing alternate attack plans. **Figure 3.1** presents the timeline for each SPI trial in the experiment. Each trial starts at the PRE-IP point. From waypoint 47 to 49 the RN in the lead aircraft evaluates SPI imagery. Based on his imagery evaluation, the RN selects the appropriate attack plan for own and trail aircraft. **Figure 3.1** also shows five possible flight paths for SPI (the numbered dashed lines). For each SPI run one of these five flight paths was simulated.

The lead aircraft must make the selection of an alternate attack plan prior to reaching the Decision Point (DP). The RN in the lead aircraft would change his assigned DMPI by entering a new IP through the OAS. For example, if the selected attack plan required the lead aircraft to attack DMPI 61, the RN would enter "60" and accomplish a FLYTO. The lead aircraft would subsequently transmit a radio message (e.g., "EXECUTE ALPHA") to the trail aircraft that would designate the selected attack plan.

The SPI run would be completed after the lead aircraft enters the FLYTO and subsequently calls out the selected attack plan (e.g., EXECUTE ALPHA, EXECUTE BRAVO).

Figure 3.3 presents an overview of the activities associated with each SPI trial. Initially the RN is presented a screen which shows the SPI ingress angle relative to the target area. He is also informed at this time if the trial is a single or double pass trial. The RN starts the trial by pressing any key on the keyboard. SPI imagery is subsequently presented to the RN in a continuous manner. During the simulated presentation of "real-time" imagery the RN evaluates the SPI imagery, marks frames of interest (he can return to a marked frame during review), and selects when to stop the presentation of the "real-time" imagery. After the RN stops the presentation of "real-time" imagery he can review the imagery to reach a final decision. After the RN has decided what target configuration is present in the railyard, he consults his pre-planned options, makes the appropriate IKB entry, and calls out the selected plan. In the simulation, the RN enters the selected plan with the keyboard in order to facilitate data analysis. After the trial is completed the RN enters a confidence rating with the keyboard that ranges between 1 (not at all confident) to 7 (very confident).

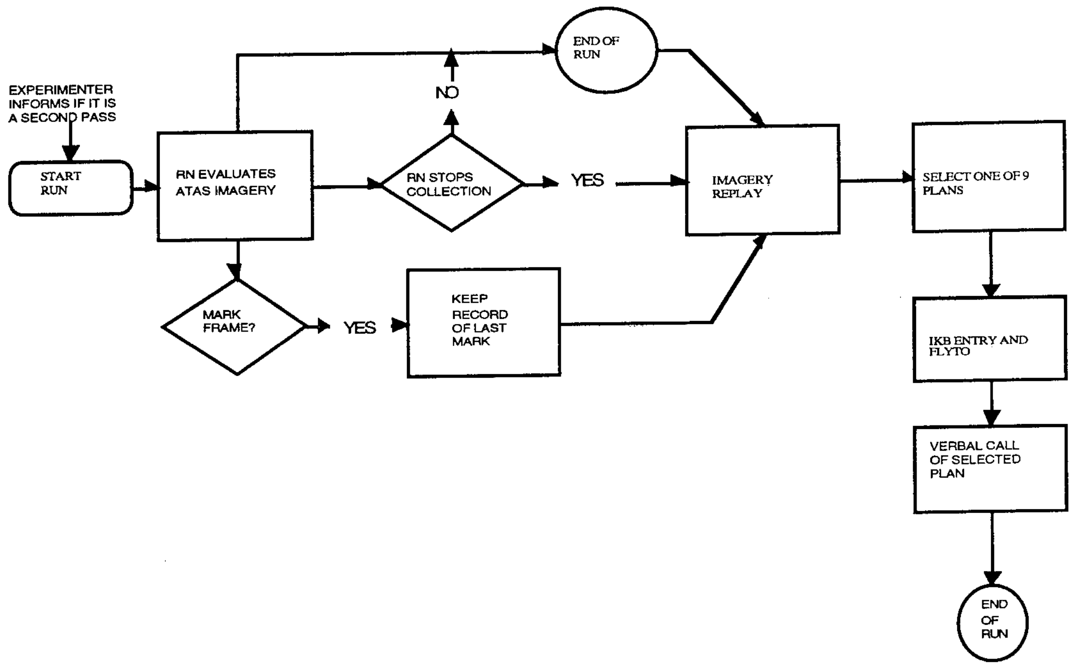


Figure 3.3. Sequence of activities for one SPI simulation trial.

Stimulus Population

Figure 3.4 presents a photograph of the railyard target area. The photograph was digitized and entered into the data base of a Compuscene IV image processing system. The railyard was embedded into a scene that contained an urban area with buildings and roads.

Figure 3.4. Photograph of the Target Area.

The railyard and surrounding area constituted the stimulus that was used to generate the stimulus population. A test stimulus consisted of approximately 30 seconds of imagery that began outside of the developed area (forest area) and ended shortly after overflying the target area.

The overfly simulated a SPI traveling at a velocity of 415 knots. Other parameters associated with SPI are presented in Section 2 of this report.

In order to generate different target configuration of railcars, models of the railcars were moved about the railyard. Three types of configurations were generated: (a) equal distribution of targets; (b) single area (DMPI) biased, and (c) two areas biased. The following presents a description of each target configuration.

(a) Equal Distribution of Targets: In this condition the railcars were equally distributed throughout the railyard i.e., equal number of railcars in each DMPI. The cars were distributed under either a low density (less than 15 railcars in each DMPI) or high density (more than 16 railcars in each DMPI). Two different target variants were generated for the low and high density distributions in order to obtain a larger number of unique target configurations. Therefore, there were two unique target configurations for both the Equal/low (E_L) and Equal/high (E_h) target configurations.

(b) Single Area Biased (B_1): There were four unique target configurations for the B_1 condition. The biased area corresponded to the four DMPIs on the target area. A biased area was defined as a DMPI with a high density of railcars where the other area contained a low density of railcars.

(c) Two Areas Biased (B_2): There were four unique target configurations for the B_2 condition. For each of the four configurations, two different DMPIs were populated with a high density of railcars.

Figure 3.5 presents a graphic for each of the above target configurations. This figure also contains information regarding RN decisions, verbal calls and integrated keyboard (IKB) entries that will be discussed under Procedures. Configurations 3 and 11 were not developed for the simulation. They represented possible configurations

which were included for completeness. In the simulation the RNs were given a job aid similar to **Figure 3.5**. The purpose of this job aid was to support RN decisions regarding the configuration they thought was present in the stimulus. Although they were given 11 options from which to select, only nine configurations were represented in the stimulus set.

The combination of target configuration and SPI ingress angle resulted in a total of 48 stimuli. **Table 3.1** presents an overview of the variables that generated the target stimulus population. Note that under each ingress angle there are nine unique stimuli: 1(a&b), 2(a&b), 3, 4, 5, 6, 7, 8 and 9.

Table 3.1. Target stimulus population.

	SPI INGRESS ANGLES				
Target Configuration	1	2	3	4	Frequency
Equal Low (E_L)	1a 1b	1a 1b	1a 1b	1a 1b	8
Equal High (E_h)	2a 2b	2a 2b	2a 2b	2a 2b	8
Single Bias (B_1)	3 4 5 6	3 4 5 6	3 4 5 6	3 4 5 6	16
Dual Bias (B_2)	7 8 9	7 8 9	7 8 9	7 8 9	12
					48

Stimuli were selected from the above population in the preparation of a training and test set of trials.

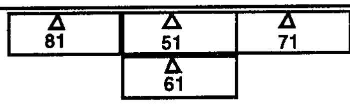
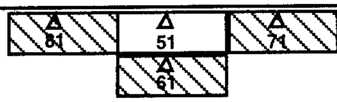
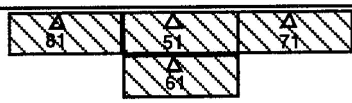
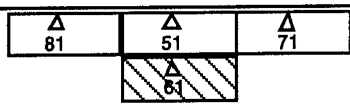
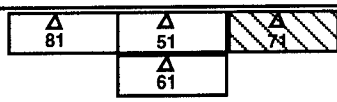
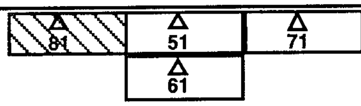
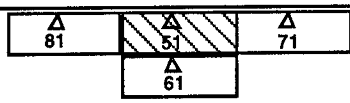
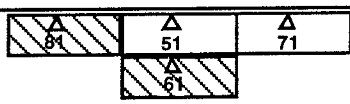
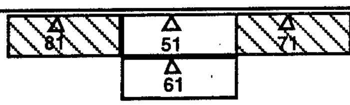
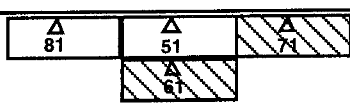
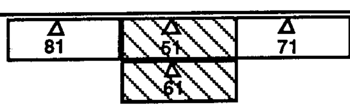
CONFIG.	TARGET CONFIGURATION	RN DECISIONS	PLAN	LEAD AIRCRAFT ENTRY
1		• No targets of interest • Select alternate target(s)	Execute plan "Alpha"	FLYTO 90 <ENTER>
2		• CONCENTRATED IN DMPIs 71, 81, and 61 • ALTERNATE plan	Execute plan "Bravo"	FLYTO 80 <ENTER>
3		• concentrated in ALL DMPIs • GO WITH ORIGINAL PLAN	Execute plan "Charlie"	FLYTO 50 <ENTER>
4		• concentrated in DMPI 61 • ALTERNATE PLAN	Execute plan "Delta"	FLYTO 60 <ENTER>
5		• concentrated in DMPI 71 • ALTERNATE PLAN	Execute plan "Echo"	FLYTO 70 <ENTER>
6		• concentrated in DMPI 81 • ALTERNATE PLAN	Execute plan "Foxtrot"	FLYTO 80 <ENTER>
7		• concentrated in DMPI 51 • ALTERNATE PLAN	Execute plan "Golf"	FLYTO 50 <ENTER>
8		• concentrated in DMPIs 61 and 81 • ALTERNATE PLAN	Execute plan "Hotel"	FLYTO 80 <ENTER>
9		• concentrated in DMPIs 71 and 81 • ALTERNATE PLAN	Execute plan "India"	FLYTO 80 <ENTER>
10		• concentrated in DMPIs 61 and 71 • ALTERNATE PLAN	Execute plan "JULIET"	FLYTO 70 <ENTER>
11		• concentrated in DMPIs 51 and 61 • ALTERNATE PLAN	Execute plan "KILO"	FLYTO 50 <ENTER>

Figure 3.5. The eleven possible target configurations.

EXPERIMENTAL DESIGN

The previous paragraphs contained in this section have described the mission that was developed to evaluate the SPI concept, the sequence of activities for each SPI simulation trial, and the stimulus population. The following presents the experimental design (i.e., the independent variables, dependent variables, apparatus, test subjects, and procedures) that was used for the man-in-the-loop part task simulation.

Independent Variables

The experimental design was a two factor within subjects design. The factors were the number of SPI overflys of the target area (single pass or dual pass) and the target configuration. The conditions (i.e., number of overflys and target configuration) within each set of 32 trials were presented in a random order.

There were two independent variables in the study; (a) number of SPI target overflys, and (b) target configuration. For the SPI target overflys there were two conditions: single pass and dual pass of the target area. Under the single pass condition the operator; (a) viewed the imagery from one overfly of the target area , (b) reviewed the imagery using the playback mode; (c) made a decision regarding the presence and location of railcars; and (d) executed the response behaviors associated with the decision. In the dual pass condition, the above steps were repeated with a second pass of the target area using a different SPI ingress angle.

Stimulus Conditions

Table 3.2 presents the target configurations as a function of single and dual pass conditions. The entries in the table represent the frequency of trials under each of the four conditions. For example, the four stimuli under single-pass E_L were generated by employing the different SPI ingress angles on the unique stimuli that were summarized in **Table 3.1**. The stimuli that were selected for this study, and are summarized in **Table 3.2** , represent a subset of the overall stimulus population.

Table 3.2. Frequency of trials as a function of single and dual pass for the four different railyard configurations.

Number of SPI passes	Configurations E_L	E_h	B_1	B_2	Frequency
Single	4	4	4	4	16
Dual	4	4	4	4	16
					32

In the dual pass condition the subjects were shown two runs with the same target configuration presented with two different SPI ingress angles. The subjects were prompted on the SPI Imagery Display that the upcoming run was a dual pass. During the second overfly, the subjects were required to perform the same tasks that were accomplished during the first overfly.

A trial for the dual pass condition consisted of two consecutive runs of the same target configuration, whereas a trial for the single pass condition consisted of a single run. **Table 3.3** shows an example of six runs that comprise two trials for the single pass condition and two trials for the dual pass condition.

Table 3.3. Example of two trials for single- and dual-pass conditions.

Variables	RUNS 1	2	3	4	5	6
# of Passes	D		S	D		S
Condition	E_L		E_h	B_1		B_2
Trial	1		2	3		4
Configuration	1a	1a	2a	3	3	7
Angle	3	4	1	3	4	4

As can be seen in **Table 3.3**, the first two runs constitute a single trial for a dual pass condition. For this trial, configuration 1a (E_L) is run with SPI ingress angles 3 and 4 on two consecutive runs. The third run is a trial for a single pass condition with

configuration 2a (E_h) and ingress angle 1. The above method was used to generate 32 trials (16 for single pass and 16 for dual pass).

Our method for implementing the dual pass capability in the simulation did not take into account the flight time for the SPI to make a second pass. That is, a dual pass was simulated by presenting single pass runs for the same target configuration in consecutive order. Incorporation of the SPI second-pass flight time would require an adjustment of the timing between waypoints 47 and 49. However, our implementation presents a proof-of-concept demonstration that enabled us to derive estimates of RN decision making performance under a dual pass of the target area with different SPI ingress angles.

Dependent Variables

Performance data were recorded during the test runs. In addition, questionnaire and debrief data were collected following the experimental session.

The simulation recorded measures were the following:

(1) RN decision:

FLYTO entry for selection of new IP for own aircraft.

Selection of attack plan (1 of 11). At the end of each trial, the subject was presented a screen that requested that he enter a number between 1-11 associated with menu options of the available 11 attack plans. This was accomplished to reduce subsequent workload for the analyst.

(2) Confidence rating for decision. After completing each run, the RNs indicated their level of confidence in their decision on a seven point scale. One indicated "not at all confident" and seven indicated "very confident."

(3) For each press of the MARK button, the imagery frame number was recorded along with a time tag.

(4) The range of SPI frames that the RN reviewed along with associated time tags was recorded.

(5) The amount of time spent viewing the simulated "real-time" imagery was recorded. This was the elapsed time between the start of the trial and the RN selecting to return to the marked frame (start of imagery review).

(6) The amount of time spent reviewing SPI imagery was recorded. This was the elapsed time between the start of imagery review and the entering of the new IP, selecting to end the trial, or a time out.

The above data were used to compute the following performance measures:

(1) Percent correct decisions (%CD)

(2) Average imagery viewing time (AIVT)

(3) Average imagery review time (AIRT)

(4) Average confidence ratings (ACR)

The above measures were computed as a function of single- and dual-pass conditions for the four different configurations.

In addition to the above measures, the following measures of effectiveness (MOEs) were computed.

(1) Number of required sorties for each target configuration under the assumption of **no** SPI.

(2) Number of required sorties for each target configuration under the assumption of an available SPI. The number of sorties calculated with this method assumed a <u>perfect</u> SPI and <u>perfect decision making</u> on the part of the RN.

The experimental data from the SPI study was used to compute an adjusted value for number of required sorties. The adjustment accounted for the RN's observed decision making accuracy in the study (i.e., man-in-the-loop). For each target configuration and each subject, a %CD was computed. This was accomplished for single- and dual-pass conditions separately.

The results of the analyses of required number of sorties measures are presented in the Results Section of the report.

In addition to the above performance measures, questionnaire and debrief data were gathered. RN comments and suggestions were solicited in the following areas: (a) tactical use of the SPI concept, (b) the controls and displays, (c) the mechanization of the concept from a crewstation point of view, (d) rationale for decision making activities during the test trials, and (e) suggestions for improving the concept.

The results of the questionnaire and debriefing data are presented in the Results Section (Section 4) of this report.

Apparatus

The SPI part-task simulation device is pictured in **Figure 3.6**. The device includes two displays; a SPI Imagery Display, and a Primary Data Display (PPD) that presents information regarding the start and end of each SPI run.

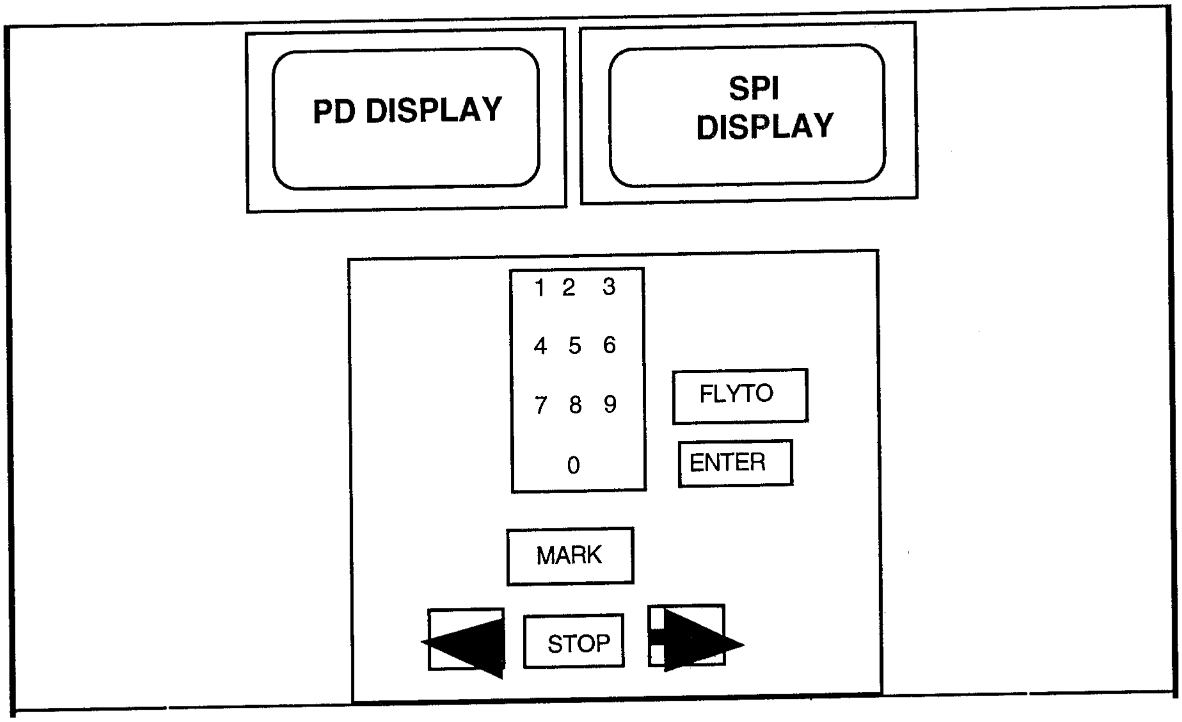


Figure 3.6. SPI part-task device RN controls and displays.

An IBM pc keyboard was modified to provide the RN an interface to SPI. **Table 3.4** presents a listing of the controls and functions on the modified keyboard. The experiment was run on an IBM pc computer with a video disk for image storage. Imagery on the video disk was presented on the SPI Imagery Display which was a 9" monochrome monitor. The IBM pc was also connected to the PPD for presentation of experiment relevant information during the study.

Table 3.4. Description of RN part-task simulator controls and functions.

Keyboard Controls	Functions
(MARK) Key: Single action push button.	Marks a specific SPI frame for subsequent imagery review.
(LEFT) Key: Single action push button marked with left arrow.	Dual function: (1) stops display of real time imagery, and (2) returns subject to "MARK" frame.
(RIGHT) Key: Single action push button marked with right arrow.	During replay mode, allows subject to move forward through imagery.
(STOP) Key: Single action push button.	Used to freeze or stop imagery at a particular point of interest.
(0-9) Keys: Single action push buttons.	Number pad that allows subject to enter two digit number associated with attack plan. Also allows for entry of confidence rating.
(FLYTO) Key: Single action push button.	Allows subjects to select alternate IPs.
(ENTER) Key: Single action push button.	Allows subjects to execute commands.

Subjects

A total of 12 subjects participated in the study. The subjects were B-52 RNs with an average of 2870 hours of flight time. These RNs were not on active flight status at the time of the study and were stationed at Wright-Patterson AFB. Each subject participated in a 2 hr experimental test session.

Procedure

The subjects were presented the 32 trials in a single experimental session that lasted approximately 2 hours. The session included: (1) SPI concept briefing, (2) mission briefing, (3) training trials to familiarize subjects with the procedure and imagery, (4) the 32 test trials, and (5) a study debrief and questionnaire.

Appendix B presents a copy of the mailer sent to subjects prior to their participation in the study. After arriving at the laboratory, instructions for the SPI experiment were presented (Appendix C). The material in Appendix C was supplemented with a videotaped briefing that presented an overview of the SPI concept and the mission used in the study.

SPI training consisted of the following steps: (1) the subjects were presented with a table-top discussion that reviewed; (a) the mission time-line, (b) decision making requirements, (c) controls and displays, and (d) each trial sequence; and (2) the subjects were provided hands-on training on the SPI part-task device

The subjects were run through 8 training trials that consisted of an equal number of single and dual pass conditions. The training trials were run on the SPI part-task device using a subset of the railyard imagery (imagery used in the training trials was not employed in the experimental trials).

During the training trials the experimenter interacted with the subjects to ensure that they understood the experimental procedures. In some cases the training trials were repeated to provide the RNs with additional familiarization with the imagery and procedures.

Table 3.5 presents the sequence of events for each SPI run. Each run lasted approximately two minutes. SPI simulated imagery collection lasted approximately 25-30 seconds. The subject then had an additional 1 minute and 30 seconds to replay the imagery, reach a decision with respect target location and density, select the appropriate railyard configuration by entering a FLYTO and plan, and entering a confidence rating.

Table 3.5. Sequence of events for each SPI run.

EVENT	DISPLAY	CONTROL
- Start of run	- PDD shows the message "HIT ANY KEY" - A graphic is presented that shows the SPI ingress angle	- Subject presses any key on keyboard to start the trial
- Simulated SPI imagery collection	- "Real-time" SPI imagery is shown on the SPI display	- Subject marks frames if desired - Subjects can stop imagery collection and start replay
- SPI imagery replay (after subject stops imagery collection or SPI completes overfly)	- SPI display shows replayed imagery (stating from mark if one was entered or from beginning of run)	- Subject uses the (LEFT) and (RIGHT) arrow keys to move back and forth through the imagery
- RN decision (before reaching DP -- approximately 2 min allotted for imagery evaluation and decision making)	- SPI display - PDD	- Subject enters FLYTO associated with new IP - Subject enters new attack plan. -Subject enters confidence rating

Figure 3.5 that was shown under Stimulus Population, presents the 11 possible target configuration decisions (note only 9 of these configurations actually occurred in the study). Each target configuration was associated with an RN decision, FLYTO and plan entry, and confidence rating entry. This procedure allowed the RN to focus on the task of imagery evaluation and selection of the appropriate pre-planned attack plan based on the SPI imagery interpretation. In addition, this procedure would result in a minimal amount of communication between lead and trail aircrafts. The attack options would have been briefed to the entire strike force and therefore the message "EXECUTE ALPHA" would result in all aircraft attacking their pre-designated targets (DMPIs or alternate targets if required). This procedure was developed in cooperation with Air Force RNs and SAC Tactics School personnel. It represents a notional tactic for this proof-of-concept study. The Results Section of the report contains comments and suggestions from the subject RNs regarding this procedure.

Following the training trials, the subjects were presented with 32 experimental trials. These were the test trials where performance data were collected. The running of the test trials lasted approximately 1 hr.

Following the test trials, the subjects were debriefed using a structured debrief/questionnaire procedure. Appendix D presents the SPI interview and questionnaire materials.

SECTION 4
RESULTS

This section presents the results of analyses performed on behavioral and subjective data from the SPI part-task simulation. During the simulation, the following measures were collected:

(a) Percent correct decisions (%CD)
(b) Average imagery viewing time (AIVT)
(c) Average imagery review time (AIRT)
(d) Average confidence ratings (ACR)

PERFORMANCE MEASURES

Separate two-way within subjects analysis of variance (ANOVA) procedures were performed on the above four performance measures. The within factors were number of SPI passes (PAS) and configurations (CONFIG). The analyses were performed under two different conditions. Inspection of the data revealed that a large number of errors were recorded for those stimuli that included DMPI 61. This was an area of the target that presented poor target to background contrast. Therefore, analyses were conducted with and without DMPI 61 included.

With the removal of DMPI 61, one of the target configurations was removed from the analyses. This was the Equal/High distribution of targets. Removal of DMPI 61 also reduced the sample size for the other target configurations; that is, trials that included DMPI 61 for target configurations Equal/Low, Bias 1, and Bias 2 were removed from the analyses.

PERCENT CORRECT DECISIONS (%CD)

Percent Correct Decisions With DMPI 61

On the average the subjects responded with an accuracy rate of 53%. This is well above chance level performance equal to 9.09%. Chance level performance is based on the probability of making a correct response given the

11 response alternatives (i.e., 1/11 or 9.09%). **Figure 4.1** presents average percent correct decisions as a function of target configuration and number of passes. The ANOVA results indicated that there were no statistically significant main effect for the PAS and CONFIG variables on the accuracy of decision making, $F(2,22)= 1.40$, $p>.05_{ns}$, and $F(3,33)= 1.47$, $p>.05_{ns}$, respectively. In addition, the interaction between PAS and CONFIG was not statistically significant, $F(6,66)= 1.04$, $p>.05_{ns}$.

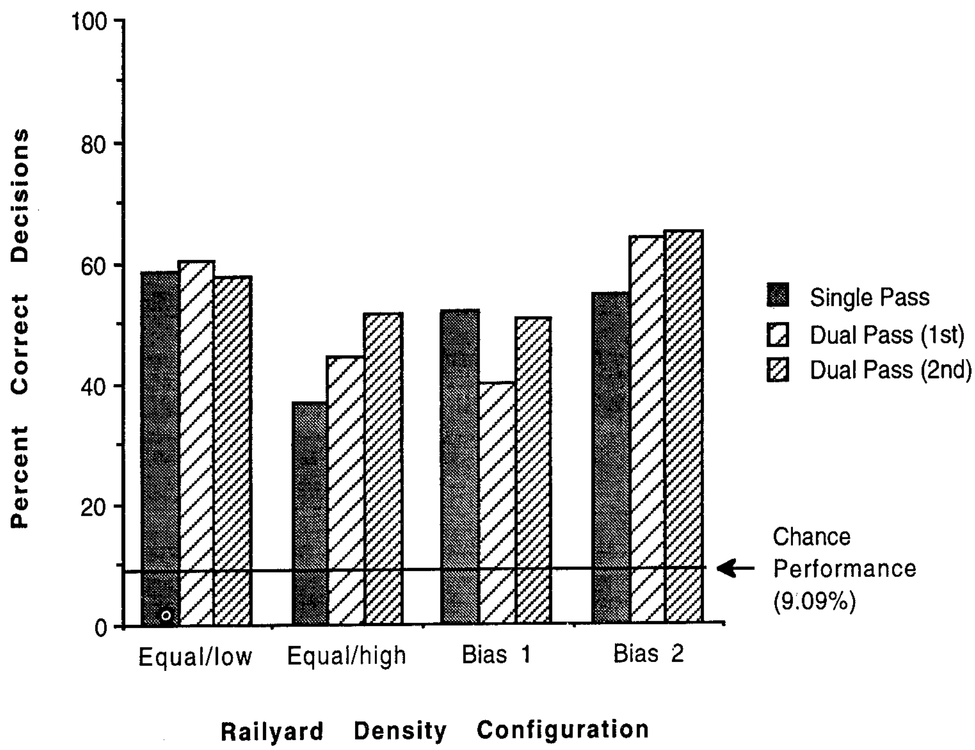


Figure 4.1. Average percent correct decisions as a function of number of SPI passes and target configuration (DMPI 61 included).

Percent Correct Decisions Without DMPI 61

On the average the subjects responded with an accuracy rate of 73%. This is well above chance level performance equal to 9.09%. **Figure 4.2** presents average percent correct decisions as a function of target configuration and number of passes. The ANOVA results indicated that there were no statistically significant effect for the PAS variable on the accuracy of decision making, $F(2,22)= 2.18$, $p>.05_{ns}$. However, the CONFIG variable had significant effect on

the accuracy of decision making, $F(3,33) = 13.70$, $p < .001$. The interaction between PAS and CONFIG was not statistically significant, $F(6,66) = 0.73$, $p > .05_{ns}$. The significant effect for CONFIG showed that subjects performed at a 95.83% accuracy for the two area biased configuration relative to 58.80% and 62.96% for the equal and one area biased configurations, respectively.

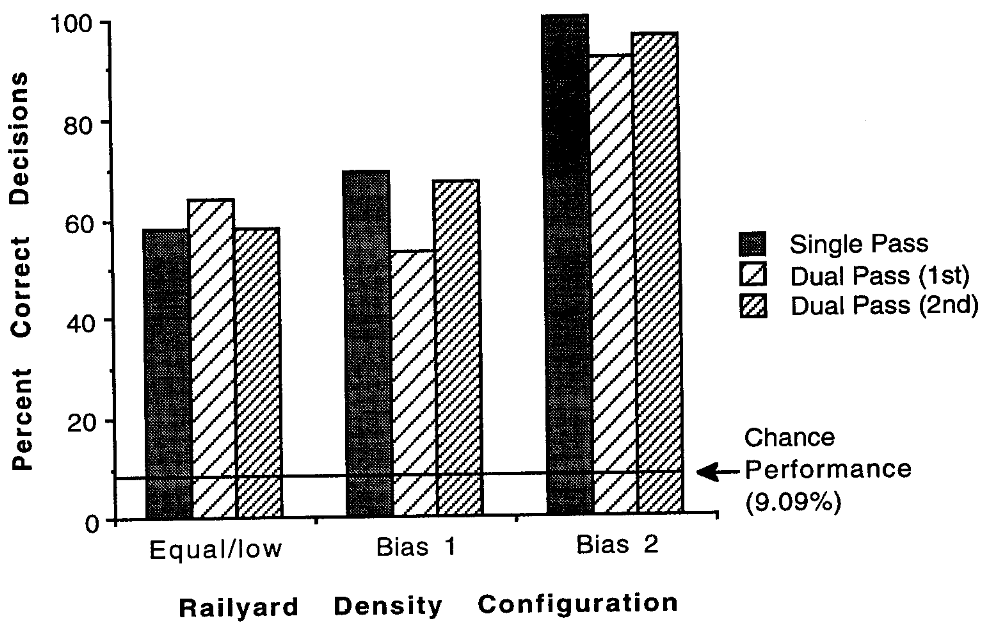


Figure 4.2. Average correct decisions as a function of number of SPI passes and target configuration (DMPI 61 not included).

<u>Percent Correct Summary</u>

Removal of DMPI 61 from the analyses resulted in a 20% increase in the average accuracy of decision making. Removal of DMPI 61 also resulted in a statistically significant detection effect for the CONFIG variable (there were no statistically significant effects when DMPI 61 was included in the analysis). When the low contrast target was removed from the analysis (DMPI 61); (a) overall accuracy was shown to increase, and (b) differences in response accuracy among target configurations were magnified. The inclusion of DMPI 61 represented a treatment analogous to the application of camouflage. That is, the target to background contrast was reduced and the subjects were less able to accurately detect the targets. Equally important was the lack of any

decision enhancement as a function of a second pass over the target area. That is, decision quality was equivalent for single and dual passes.

AVERAGE IMAGERY VIEWING TIME (AIVT)

Average Imagery Viewing Time With DMPI 61

Figure 4.3 presents average imagery viewing time as a function of target configuration and number of passes. The analyses showed that the PAS variable did not have a significant effect on the subject's imagery viewing time, $F(2,22)= 2.73$, $p>.05_{ns}$. On the other hand, the CONFIG variable had a significant effect on the subject's imagery viewing time, $F(3,33)= 3.95$, $p<.05$. There was a statistically significant interaction between PAS and CONFIG, $F(6,66)=2.63$, $p<.05$. As **Figure 4.3** shows, the subjects spent more time viewing the imagery for the first pass of the dual-pass condition for configurations that bias one or two DMPIs relative to the equal target distribution conditions.

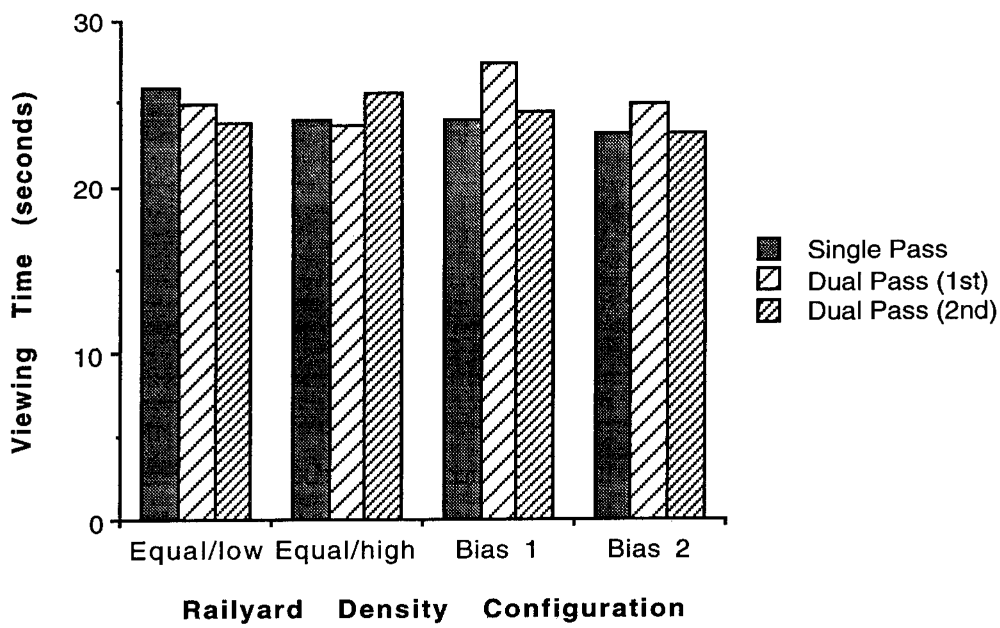


Figure 4.3. Average imagery viewing time as a function of number of SPI passes and target configuration (DMPI 61 included).

Average Imagery Viewing Time Without DMPI 61

Figure 4.4 presents average imagery viewing time as a function of target configuration and number of passes. The analyses showed that the PAS and CONFIG variables did not have a significant effect on the subject's imagery viewing time, $F(2,22)= 1.07$, $p>.05_{ns}$, and $F(3,33)= 0.59$, $p>.05_{ns}$, respectively. Also, the interaction between PAS and CONFIG was not statistically significant, $F(6,66)= 0.80$, $p>.05_{ns}$. When DMPI 61 is removed from the analyses, the subjects appear to view the imagery for approximately 25.43 sec. and this does not differ significantly as function of PAS or CONFIG.

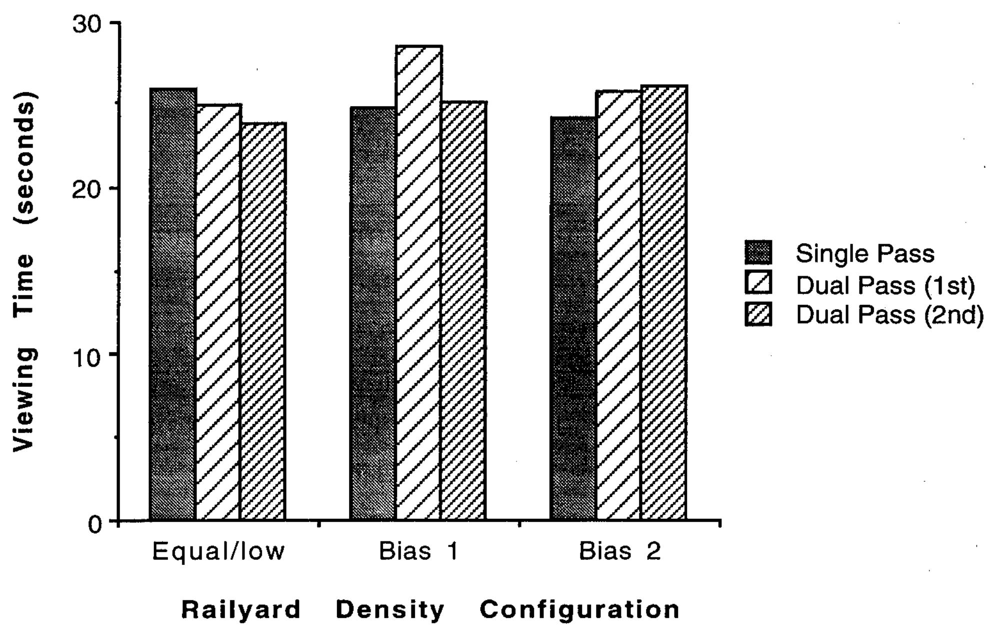


Figure 4.4. Average imagery viewing time as a function of number of SPI passes and target configuration (DMPI 61 not included).

Average Imagery Viewing Time Summary

Removal of the DMPI 61 resulted in the attenuation of the interaction between PAS and CONFIG. This is due to the fact that the Equal/high target distribution condition was removed from the analyses. In addition, the pattern of results was changed for target configuration Bias 2 but not Equal/low and Bias 1 (Compare

Figure 4.3 and **Figure 4.4**). The viewing time for target configuration Bias 2 was nearly equal under the first and second pass of the SPI.

AVERAGE IMAGERY REVIEW TIME (AIRT)

Average Imagery Review Time With DMPI 61

Figure 4.5 presents average imagery review time as a function of target configuration and number of passes. The analyses showed that the PAS variable did have a significant effect on the subject's imagery review time, $F(2,22)= 11.92$, $p<.001$. On the other hand, the CONFIG variable did not have a significant effect on the subject's imagery review time, $F(3,33)= 1.60$, $p>.05$. There was a statistically significant interaction between PAS and CONFIG, $F(6,66)=2.32$, $p<.05_{ns}$. The subjects spent significantly less time reviewing the imagery during the second pass of the dual-pass condition relative to the other conditions. Furthermore, this is most evident under the one and two DMPI biased conditions.

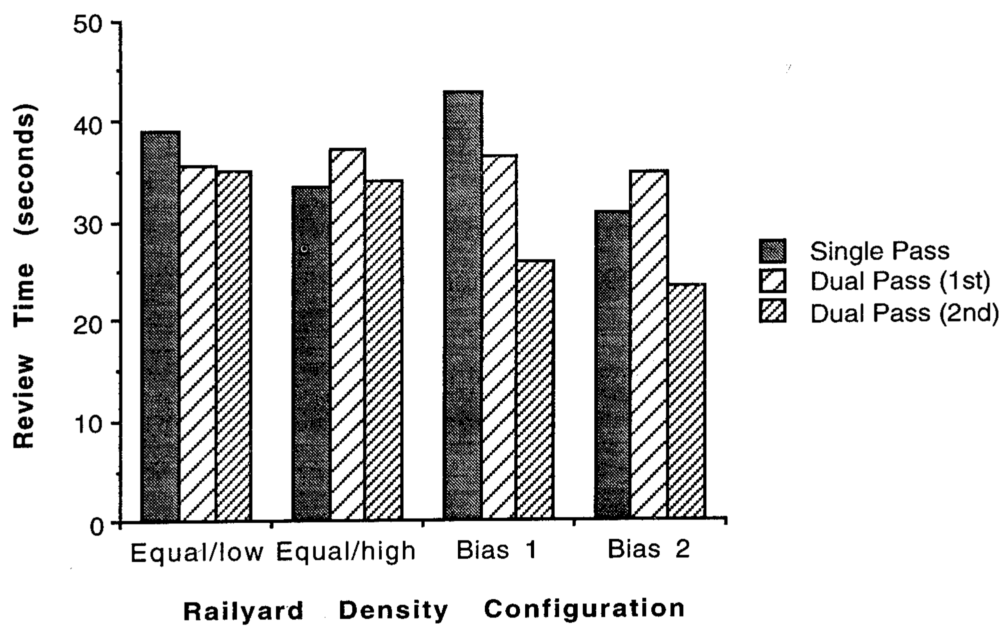


Figure 4.5. Average imagery review time as a function of number of SPI passes and target configuration (DMPI 61 included).

Average Imagery Review Time Without DMPI 61

Figure 4.6 presents average imagery review time as a function of target configuration and number of passes. The analyses showed that the PAS variable did have a significant effect on the subject's imagery review time, $F(2,22)= 5.29$, $p<.01$. Also, the CONFIG variable did have a significant effect on the subject's imagery review time, $F(3,33)= 3.91$, $p<.05$. There was a statistically significant interaction between PAS and CONFIG, $F(6,66)=4.81$, $p<.01$. The subjects spent significantly less time reviewing the imagery during the second pass of the dual-pass condition relative to the other conditions. Furthermore, this is most evident under the one and two DMPI biased conditions. Also, the single pass condition showed much shorter imagery review times under the Bias 2 configuration relative to the other conditions.

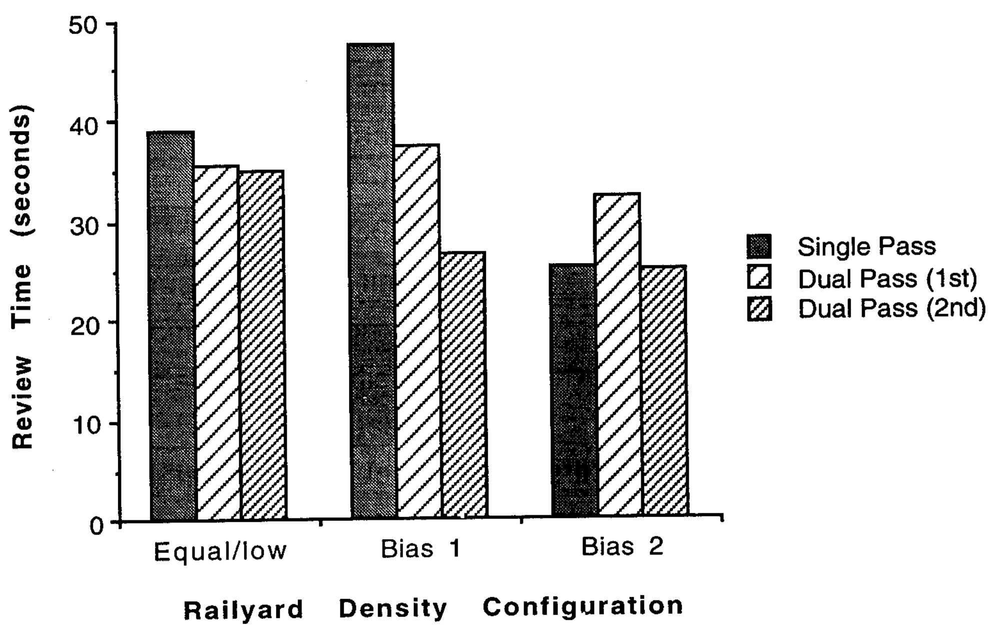


Figure 4.6. Average imagery review time as a function of number of SPI passes and target configuration (DMPI 61 not included).

Average Review Time Summary

Removal of DMPI 61 did not significantly alter the effects found for average imagery review time. That is, under both analyses the subjects were shown to spend significantly less time reviewing the imagery during the second pass of the dual-pass condition relative to the other conditions. The analyses without DMPI 61 did reveal a significant effect for the CONFIG that was not found when DMPI 61 was included. Removal of the low contrast target (DMPI 61) revealed that the subjects spent less time reviewing the imagery for the Bias 2 target configuration relative to configurations Equal/low and Bias 1. The low contrast target may have been analogous to a camouflaged target where subjects require more time to confirm target acquisition.

AVERAGE CONFIDENCE RATING (ACR)

Average Confidence Rating With DMPI 61

Figure 4.7 presents average confidence rating as a function of target configuration and number of passes. The analyses showed that the PAS variable had significant effect on the subject's confidence ratings, $F(2,22) = 7.59$, $p < .01$. Also, the CONFIG variable had a significant effect on the subject's confidence ratings, $F(3,33) = 4.77$, $p < .01$. There was not a statistically significant interaction between PAS and CONFIG. The analysis of the effect for PAS showed that the subjects were most confident under the second pass of the dual-pass condition relative to the single pass and the first pass of the dual-pass (Dunn post-hoc test with an alpha of .05 was used to examine the differences among means. This is the test used for all subsequent post-hoc tests between means for significant main effects). The difference in confidence ratings between the single pass and first pass of dual-pass was not statistically significant. For the CONFIG variable the subjects were significantly more confident under the two area biased condition relative to the low density of target condition.

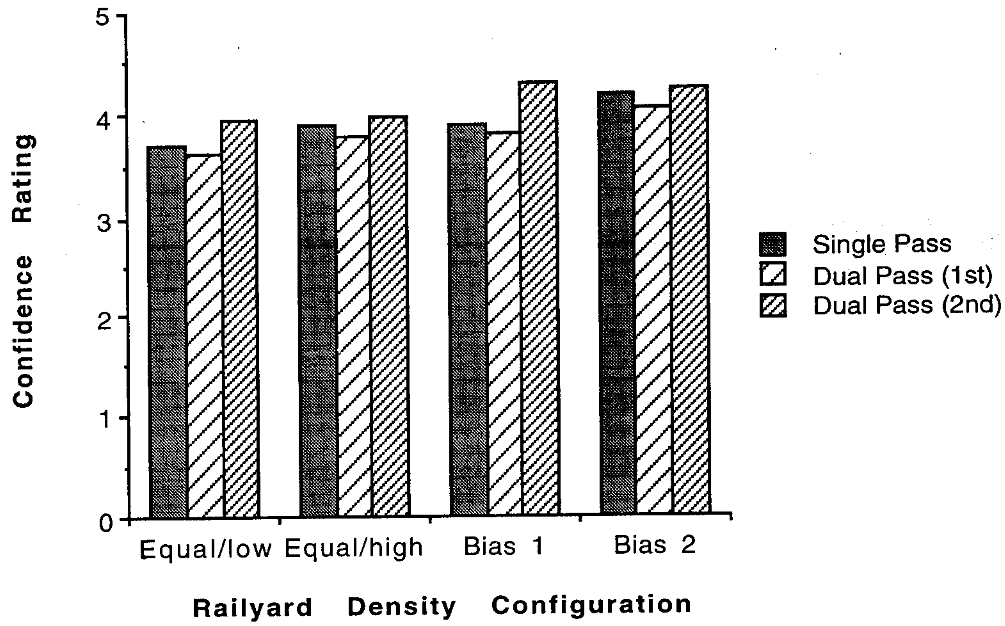


Figure 4.7. Average confidence as a function of number of SPI passes and target configuration (DMPI 61 included).

Average Confidence Rating Without DMPI 61

Figure 4.8 presents average confidence rating as a function of target configuration and number of passes. The analyses showed that the PAS variable had significant effect on the subject's confidence ratings, $F(2,22)= 6.45$, $p<.01$. Also, the CONFIG variable had a significant effect on the subject's confidence ratings, $F(3,33)= 8.41$, $p<.01_{ns}$. There was not a statistically significant interaction between PAS and CONFIG, $F(6,66)=1.82$, $p>.01$. The analysis of the effect for PAS showed that the subjects were most confident under the second pass of the dual-pass condition relative to the single pass and the first pass of the dual-pass The difference in confidence ratings between the single pass and first pass of dual-pass was not statistically significant. For the CONFIG variable the subjects were significantly more confident under the two area biased condition relative to the low density of target condition.

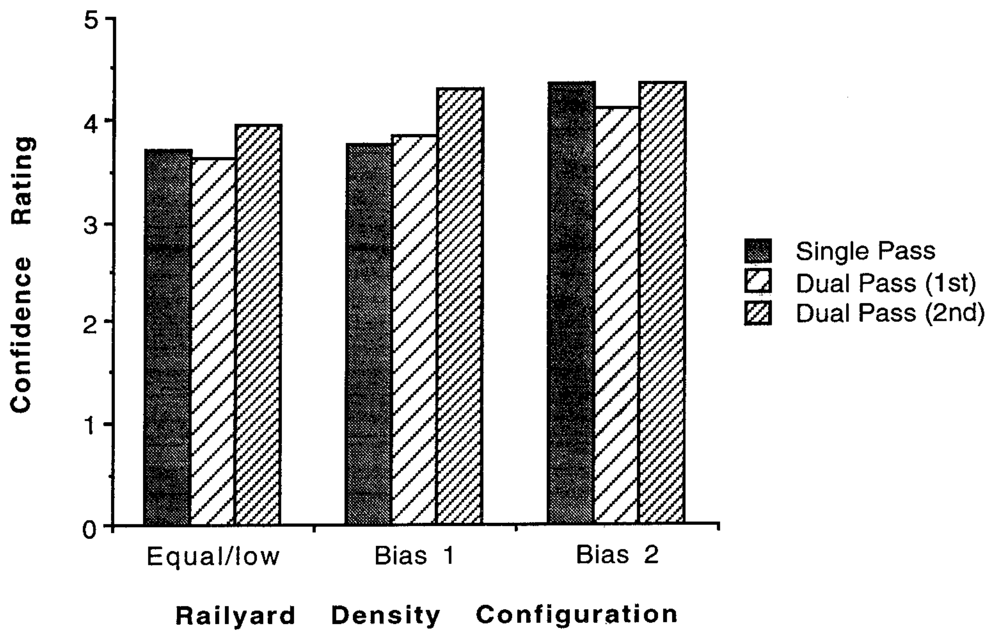


Figure 4.8. Average confidence ratings as a function of number of SPI passes and target configuration (DMPI 61 not included).

Average Confidence Rating Summary

The removal of DMPI 61 did not have an effect on the results of the statistical tests. The PAS and CONFIG main effects were shown to be statistically significant under both analyses. The subjects were more confident under the second pass of the dual-pass condition with and without DMPI 61. Also, the subjects were more confident with configuration Bias 2 relative to configuration Equal/low. Comparison of **Table 4.1** and **Table 4.2** reveal that with DMPI 61 included, the correlation between confidence and accuracy was essentially equal to zero (0.00231). When DMPI 61 was removed, the correlation between confidence and accuracy was positive (+0.24) and of low magnitude. Ratings of confidence appear to be more strongly related to how much time the subjects spent reviewing the imagery (correlations of -0.54 and 0.52 between confidence and review time with and without DMPI 61, respectively). The analyses suggests that accuracy and confidence ratings were not related in this study. The removal of DMPI 61 had significant effect on accuracy without an associated increase in confidence.

Correlation Among Variables With DMPI 61

Table 4.1 presents the correlation among the simulation variables. The only statistically reliable correlation is between confidence and review time. The more confidence expressed by the subjects, the less time was spent reviewing the imagery.

Table 4.1. Correlation among the simulation variables (DMPI 61 included).

	Confidence	Viewing Time	Review Time	% Correct
Confidence	****	-0.00012	-0.53560	0.00231
Viewing Time		****	-0.04797	-0.01907
Review Time			****	0.01144
% Correct				****

Correlation Among Variables Without DMPI 61

Table 4.2 presents the correlations among the simulation variables. When DMPI 61 is removed, the correlation between confidence and percent correct was found to be significant. Higher accuracy decisions were associated with higher confidence ratings. Review time and percent correct reliably correlated. Shorter review times were associated with higher accuracy. Finally, relationship between confidence and review time was once again found to be statistically significant. Shorter imagery review times were associated with higher confidence ratings.

Table 4.2. Correlation among simulation variables (DMPI 61 not included).

	Confidence	View Time	Review Time	% Correct
Confidence	****	0.03648	-0.5169	0.23724
View Time		****	-0.09894	-0.06460
Review Time			****	-0.21608
% Correct				****

PERFORMANCE MEASURES SUMMARY

The above analyses identified that a dual-pass configuration does not have a significant impact on performance relative to a single-pass SPI. The imagery evaluation behavior varied as a function of single- versus dual-pass; however, accuracy remained relatively unchanged. These analyses illustrate the significant impact of target configuration and target to background contrast on performance. When DMPI 61 was included in the analyses, average accuracy was approximately equal to 53%. This level of performance is well above chance (i.e., 9.09%) and would suggest that an SPI would result in a force multiplication. Furthermore, when DMPI 61 was excluded from the analyses average accuracy increased to approximately 73%. That is, a 20% increase in accuracy was observed when the low contrast target area was removed from the analyses.

Results showed that subjects could use SPI to improve their decision process for selection of the optimum attack plan. As presented in **Figure 4.9,** the optimum attack plan was selected between 53% to 73% of the time, resulting in a substantial reduction in required number of sorties. These results are expressed as a comparison between baseline performance and perfect performance. **Baseline performance** is defined as follows:

(1) For a desired fractional coverage (FC) of 50%, a total of 9 sorties would be required. (Please note that this is a notional % FC for the purpose of relating simulation results to operational performance.) These numbers are based on no SPI real-time target imagery and reflect an accuracy of 9% (i.e. chance performance).

Perfect performance is defined as follows:

(2) If one assumes perfect information (i.e., exact knowledge of where the targets are located in the railyard) and the attack is concentrated to an optimum DMPI, then for a desired FC of 50%, a total of 3 sorties would be required. This would represent a force

multiplication in that there is a 67% reduction in required number of sorties to achieve the desired FC.

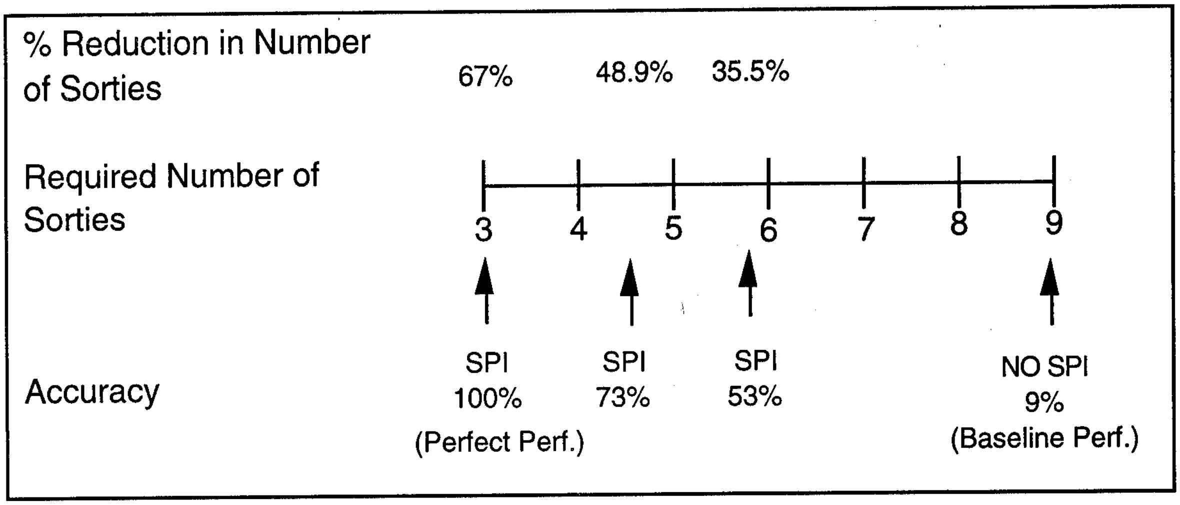


Figure 4.9. Required number of sorties as a function of target selection accuracy (This is for a notional FC).

These results suggest that a SPI with sensor resolution, flight parameters, and a man-machine interface similar to that used in this study would serve as a force multiplier. Application of our data to the modeling results for required number of sorties to achieve a desired FC suggest that SPI can decrease the required number of sorties between 36% (or 5.7 sorties) to 49% (or 4.6 sorties) based on the subjects' accuracy. These results are suggestive and would require additional modeling on empirical data for validation.

As stated previously, the variation in accuracy (53% to 73%) was not affected by the number of passes (i.e., single versus dual pass). However, the subjects reported greater confidence in their decisions for the dual pass condition relative to the single pass.

QUESTIONNAIRE AND DEBRIEF RESULTS

This section presents a discussion and summary of the responses to the questionnaire. RN responses are organized into the following three categories based on the debriefing questionnaire: (1) Decision making strategy used to evaluate the SPI imagery and evaluation of SPI part-task

device controls and displays, (2) Evaluation/comments regarding the SPI imagery and suggestions for improvements, and (3) Evaluation of SPI mission concept and tactics.

A summary of the quantitative and qualitative responses to each questionnaire item is contained in Appendix E. For each of the questionnaire rating scales, the average and modal responses are presented. In addition, the standard deviation and range of responses are also presented. Summaries of the comments are presented for each question.

Decision Making and the Controls and Displays

The SPI simulation and man-machine interface (i.e., the controls and displays) were viewed favorably by the RNs. In general, the RNs found the display prompts (i.e., ingress angle, double pass/single pass, mode, and TTG) to be useful throughout the trials. The mark imagery feature/control was used extensively by all RNs and was viewed favorably. All RNs indicated they would use the mark capability in an operational setting and would recommend implementing it in a similar fashion as was used in the study. The RNs did not like the dual function (<--) key used to (1) stop recording and (2) go to the marked frame. They felt that a dual-function key would be especially problematic under a high workload combat environment where they may be more prone to make errors. Most RNs indicated that the dual-pass capability served to reinforce their previous decisions and that they rarely changed their decisions based on a second pass over the railyard. These comments are consistent with the results for the performance data.

The RNs generally liked the notional attack plan that was used; however, the method used for recording the selected plan was not representative of a good man-machine interface. A menu of attack plans was displayed on the PPD and coded alphabetically (Alpha, Bravo, etc.) for simulating selection. RNs were required to enter a number associated with the plan of choice and depress the (ENTER) key. The process of going from alphabetic to numerically coded data introduced an unnecessary amount

of work for the RNs. This is an experimental anomaly which is not part of the SPI concept proper.

Imagery Evaluation

The RNs found the imagery to be adequate and realistic for the targeting task; however, a simulator anomaly associated with freeze frame did raise several comments. The freeze frame anomaly resulted in imagery "jitter" which reduced the RN's ability to use freeze frame for target acquisition. When asked their preference regarding the implementation of the playback/review capability, nine of the twelve subjects stated they favored the continuous transmission of the imagery as opposed to a burst snapshot presentation.

Most RNs had difficulty identifying targets in DMPI 61 because of low target to background contrast. These comments are consistent with the performance data (i.e., average percent correct decisions with and without DMPI 61 were 53% and 73% respectively).

RNs were asked to rate the realism of various aspects of the imagery. These aspects included the forest area, urban area including buildings, roads and other landmarks, and the target area (i.e., railyard) to include reference points, DMPI areas, and targets. Average responses ranged from 3.38 to 3.92 (3 = somewhat realistic and 5 = very realistic) indicating that these imagery aspects were representative for part task simulation.

SPI Concepts and Tactics

All RNs stated that the SPI mission and simplified man-machine interface implementation was adequate for demonstrating the effectiveness of the SPI proof-of-concept demonstration. Suggestions for improvement included additional attack plans; specifying decision point (DP) parameters; improving quality of video; and exploring various flying patterns such as short roll-in runs and cells of bombers abreast. In general, RNs indicated that using the SPI concept for BDA was a good idea. It was suggested that SPI be launched from the last aircraft in the

cell in order to allow time for smoke to clear before viewing the target area.

RNs were asked to suggest other types of mission in which SPI would result in an increase in mission success. Mobile targets such as moving battlefield/armies on the march, relocatable command posts, sea surveillance, SCUD missiles, and mobile launchers were mentioned by several of the RNs. One subject indicated that SPI would be particularly useful in situations where crews have insufficient reconnaissance imagery/data.

GENERAL DISCUSSION

The RNs were highly in favor of the SPI concept and their comments are consistent with the empirical results of the simulation. All RNs stated that the SPI mission, simulation, imagery, man-machine interface (i.e., the controls and displays) were adequate for demonstrating the effectiveness of the SPI proof-of-concept demonstration.

The SPI study is an initial proof of demonstration for enhancing mission effectiveness for a notional mission against a fixed target. The empirical results showed that subjects could use SPI to improve their decision process for selection of the optimum attack plan. The optimum attack plan was selected between 53% to 73% of the time, resulting in a substantial reduction in required number of sorties. Therefore, these results suggest that a SPI with sensor resolution, flight parameters, and a man-machine interface similar to that used in this study would serve as a force multiplier. Application of our data to the modeling results for required number of sorties to achieve a desired FC suggest that SPI can decrease the required number of sorties between 36% to 49% based on the subjects' accuracy. These results are suggestive and would require additional modeling on empirical data for validation.

SUMMARY

The **two-phase** Sensor Preview Imagery (SPI) concept development study entailed the application of traditional analytic and modeling techniques in the definition of the SPI concept. These analyses resulted in an initial concept that was further refined and evaluated through the use of man-in-the-loop simulation. In **Phase I** of the study, relevant mission and operational parameters for the SPI concept were defined and translated into system requirements. Parameters included platform (B-52); mission (railyard attack); sensor (EO/TV); tactics (conventional bomb run, selectable DMPIs); targets (fixed railcars, boxcars, and flatbeds); and communication (one-way sensor link). System requirements included sensor parameters such as field of view, depression angle, snapshot rate. Vehicle requirements considered altitude, speed, and minimum range of the aircraft. The purpose of **Phase II** was to test the requirements that were identified during Phase I and to verify that a system such as SPI would in fact function properly in an operational setting. Experienced B-52 radar navigators (RNs) participated in a real-time part-task simulation. An optimum attack plan, based on target location in the railyard, was specified that would result in the desired Fractional Coverage (FC) with the minimum number of sorties. Subjects were given the opportunity to modify the attack plan based on SPI imagery; or execute the planned tactic which did not take real-time target information into account.

The SPI concept, mission, and target imagery used in the man-in-the-loop simulation represents a single point along a continuum for system design and evaluation. This study demonstrates the utility of a SPI concept and that radar navigators can potentially use the information provided by a SPI to enhance mission success. Furthermore, it illustrates a unique method of employment of unmanned aerial vehicles (UAVs); that is, SPI represents a force multiplier that serves as an adjunct to the strike aircraft, providing crews with a self-contained capability for advanced reconnaissance, target acquisition, threat avoidance and bomb damage assessment with increased survivability. Typically, UAVs are pilotless reconnaissance and surveillance planes that gather information that can then be used at a later date to make targeting decisions. In contrast, SPI is a bomber-launched UAV designed to arrive in the target area only minutes before the strike aircraft, thereby providing **real time** imagery of the

target area. With this information, the strike aircraft has the opportunity to modify the mission plan in order to enhance weapon lethality. While most UAVs are based on the concept of a pilotless vehicle, SPI focuses on a man-in-the-loop concept where crewmembers make final targeting decisions based on the most current information.

In support of this SPI study, several new concepts were created. During the simulation, the lead aircraft flying in a three aircraft cell had primary responsibility for evaluating the SPI imagery and selecting one of eleven pre-planned attacks. Pre-planned attacks were developed in order to minimize real-time decision making with respect to mission planning, and to allow the RN to focus on the job of imagery evaluation. An attack plan was selected by matching the target configuration that the RN had perceived from reviewing the SPI imagery with one of eleven possible target configurations. The target configurations were keyed to the decisions that the RN needed to make in terms of: (1) selecting the DMPI for own aircraft, and (2) sending a code to the trail aircraft indicating what attack plan to execute. The concept assumed an integrated attack plan that required minimal communication between the aircraft and represents an effective methodology for managing the weapons delivery decision making process.

SECTION 5
RECOMMENDATIONS

INTRODUCTION

SPI represents a technically feasible, cost-effective, and flexible asset that can be implemented using existing technology. Although our analyses focused on implementation of SPI utilizing the current capabilities of the B-52 and associated tactics, this proof of concept study demonstrates that the SPI concept has a wide variety of applications. One of the major thrusts of the Defense Department's Science and Technology (S&T) program is precision strike: "The desire for reduced casualties, economy of force, and fewer weapons platforms demands that we locate high-value, time sensitive fixed and mobile targets and destroy them with a high degree of confidence within tactically useful timelines" (Director of Defense Research and Engineering [DDR&E], 1992). In support of this S&T precision strike thrust, on- and off-board sensor cues for a real time, flexible precision strike capability will be utilized (DDR&E, 1992). SPI represents an off-board sensor that could be housed on a UAV capable of sending imagery to assist a precision strike aircraft (ex B-1B, B-2, or F-15E) in locating, high value, time-sensitive military fixed and/or mobile ground targets.

As articulated by the Secretary of Defense:

> The old U.S.acquisition strategy placed a premium on rapid development and procurement of new systems to counter rapidly evolving Soviet capabilities. . . Under the new U.S. acquisition strategy, there will be heavy emphasis on government-supported R&D to maintain the technology base. More work will be done with prototypes to demonstrate capabilities and prove out concepts. We plan to go to [production] on fewer systems, and only after having taken the time to prove out the concept. We will rely more often on inserting new capabilities into existing platforms and upgrades, instead of building totally new systems (DDR&E, 1992).

ADDITIONAL DESIGN SIMULATIONS

There are a number of research studies that might be conducted based on the results of the SPI concept development study. First, additional **part-task, man-in-the-loop simulations** could be conducted using alternative mission/operational parameters. Our study focused on a railyard mission for a

B-52 conventional bomb run. Future studies might be conducted using a different platform (B-1, B-2, and F-15E), mission (precision strike), sensor (radar), tactics (overfly, pop-up, low-level or loiter as part of an integrated, multi-service capability), targets (mobile or fixed), threats (AAA, SAM), and/or communication (one or two-way sensor link). Second, research could be conducted using a **more complete environment** (i.e., increase fidelity level of simulation.) Synthetic environments that include a mix of real and simulated objects and imagery could be created in order to demonstrate and evaluate the most promising SPI concepts. Possible Armstrong Laboratory tools that could be utilized include: (1) B-1B Engineering Research Simulator (ERS), (2) Virtual Avionics Prototyping System (VAPS), (3) B-2 Computer Assisted Procedures Trainer (CAPT), and (4) B-2 Prototyping and Evaluation System (P&ES). These tools would allow researchers to conduct human factors evaluations in a dynamic environment in order to evaluate areas such as performance metrics, workload related impacts, procedural subsets, man-machine interface issues, and crew position assignment. Third, crew workload and mission management research might be accomplished to assess improved mission performance and potential reduction in workload exploiting a **virtual cockpit environment**. The concept of this study would examine the use of a virtual environment to provide enhanced control and display of the SPI UAV. Use of a virtual reality helmet could be used to evaluate the effectiveness of providing pilot/sensor operator control as if the system operator were on board the UAV. Finally, **in-flight simulations** that utilized canned or prerecorded imagery of an actual mission route could be conducted. Those proven SPI concepts/prototypes could then be subjected to actual flight test demonstrations.

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LIST OF ACRONYMS

AAA	Anti-Aircraft Artillery
ACR	Average Confidence Rating
AF	Air Force
AIRT	Average Imagery Review Time
AL	Armstrong Laboratory
ALT	Altitude
ANOVA	Analysis of Variance
AVIT	Average Imagery Viewing Time
BDA	Bomb Damage Assessment
CD	% Correct Decisions
C-IV	General Electric CompuScene IV
CONFIG	Railyard Configuration
CMF	Crew Mission Folder
DMA	Defense Mapping Agency
DMPI	Desired Mean Point of Impact
DP	Decision Point
EVS	Electro-optical Vision System
FC	Fractional Coverage
FLIR	Forward Looking Infra-Red
FOV	Field of View
HFOV	Horizontal Field of View
HQ SAC	Headquarters Strategic Air Command
IKB	Integrated Keyboard
IP	Initial Point
LLTV	Low Level TV
LOS	Line of Sight
MOE	Measure of Effectiveness
NM	Nautical Mile
NP	Navigation Point
NRS	Number of Required Sorties
OAS	Offensive Avionics Station
PAS	SPI Passes
PDD	Primary Data Display
PC	Personal Computer
RN	Radar Navigator
SAC	Strategic Air Command
SACTS	SAC Tactics School
SAIC	Science Applications International Corporation
SPI	Sensor Preview Imagery
STV	Steerable Television Sensor
TGT	Target
TTG	Time To Go
UAV	Unmanned Aerial Vehicle
VFOV	Vertical Field of View
WRDC/AART	Wright Research and Development Center

GLOSSARY OF TERMS

Aircraft Cell. A formation of aircraft separated by both altitude (nominally 500 feet) and distance (1 mile) treated as a single unit by both mission planners and air traffic controllers.

Apparatus. The SPI device consisting of two displays (i.e., a SPI Imagery Display and a Primary Data Display), a modified IBM keyboard, and an IBM computer with video disk for image storage.

Attack Plan. Strategy/scheme for making targeting decisions for the experimental trials. Eleven integrated attack plans were developed for use during the experiment. Each attack plan specified the appropriate targeting decision based on the railyard target distribution depicted. Attack plans were designed in order to minimize real-time decision making with respect to mission planning, and to allow the RN to focus on the the job of imagery evaluation.

Decision Point. That point during each trial at which the subject makes his rerouting selection.

Dependent Variable. Some well-defined aspect of behavior (a response) that is measured in a study. The value that is assumed is hypothesized to be dependent on the value assumed by the independent variable and thus is expected to be a change in behavior systematically related to the independent variable. The measured responses of the human/system to the stimulus conditions. The dependent variable reflects any effects associated with the manipulation of the independent variable.

Depression Angle. The angle from the local horizontal to the line of sight of the optical center of the field of view.

Desired Mean Point of Impact (DMPI). The centerpoint of each of the four designated railyard target areas.

Experimental Design. A specific plan used to systematically vary independent variables and noting consequent changes in dependent variables.

Field of View. The angular subtense of the imaging area of the SPI sensor.

Footprint. The dimensions of the patch of ground appearing in the image.

Fractional Coverage (FC). The percentage of the target area (i.e., railyard) which is covered (i.e., imaged) during the sensor acquisition process.

Independent Variable. An aspect of the testing environment that is empirically investigated for the purpose of determining whether or not it influences the experimental outcome. Test variables or stimuli deliberately varied or controlled within the experiment to determine their effects on the dependent variables.

Job Aid. Any device, manual, or guide used on the job to facilitate performance. A job aid is something which guides an individual's performance on the job so as to enable him to do something which he was not previously able to do, without requiring him to undergo complete training for the task.

Sortie. The number of aircraft in single attack formation.

Standoff Range. A predetermined range to target which serves as the launch point for long range weapons.

Stick. A single aircraft release of a bomb train. The anticipated ground area which will be covered by the bomb pattern.

Test Subjects. The B-52 radar navigators (RNs) that participated in the SPI study.

Trial. A discrete data collection event consisting of a single set of independent and dependent variables.

APPENDIX A
ORIENTATION MAILER

SENSOR PREVIEW IMAGING (SPI) ORIENTATION MAILER

Content Highlights

SUBJECT: Sensor Preview Imaging (SPI) Study

TO: Subject's Name

1. The Armstrong Laboratory at Wright-Patterson AFB, Ohio, is conducting a study called Sensor Preview Imaging (SPI) Study. The purpose of this study is to investigate the potential of an air launched off-board sensor platform for SAC conventional and other strategic bomber operations. In order to support this goal, the Armstrong Laboratory will be relying heavily on SAC aircrew input. Therefore, your input as a subject during this study is essential.

2. The enclosed handout is designed to acquaint you with the concept of SPI, our study objectives, the simulated mission that will be presented, and the schedule you will follow. Although you will receive a much more detailed explanation of the SPI study upon your arrival, it is important that you review these materials carefully prior to the day of the study.

3. The SPI study will be conducted at Wright-Patterson AFB, Area B, Building 248, Room 109. You will be contacted to set up an individual time for your participation.

4. I look forward to your involvement in this SPI study. Your input will directly impact the success of this important SAC effort. If you should have any questions, please contact Ms. June Skelly (DSN 785-8823).

William Marshak, Lt. Col., USAF
Chief, Crewstation Integration Branch
Human Engineering Division

(U) THE SENSOR PREVIEW IMAGING (SPI) CONCEPT

(U) The SPI concept involves the use of an air-launched, autonomous vehicle equipped with off-board sensors designed to support conventional and other strategic bomber operations. The purpose of SPI is to provide bomber aircrews with a self-contained capability for advanced reconnaissance, and bomb damage assessment with increased survivability.

(U) A classified briefing on the SPI concept was presented to HQ SAC in May of 1989. Shortly thereafter Armstrong Laboratory scientists and SAC Tactics School personnel received a HQ SAC/XRH, DOO, XOB coordinated endorsement for the development of the SPI concept. Therefore, this study represents the next step in investigating the potential of the SPI concept.

(U) As depicted in Figure 1, Concept for New Targeting Device and Figure 2, Operational Concept, SPI consists of an expendable remote vehicle carried by an attacking aircraft, a B-52 for this study. The SPI missile would be launched to arrive in the target area prior to the attacking aircraft. SPI would send transmissions (i.e., imagery of the target area) back to the bomber, thereby providing the aircrew with a pre-look to verify target position, status, and defensive countermeasure employment. With this information, the strike aircraft may choose to modify the mission plan for threat avoidance (potentially improving survivability of the strike vehicle), and/or alter weapon delivery programming to enhance weapon lethality.

Figure 1. <u>Concept For New Targeting Device</u>

Figure 2. Operational Concept

(U) In summary, SPI may offer bomber aircrews the following advantages:

- Advance look at the target area
- Increased threat avoidance capability
- Autonomous targeting capability
- Battle damage assessment capability

(U) STUDY/EXPERIMENT OBJECTIVES

(U) The primary objective of this study is to analyze the utility of the SPI concept within the framework of enhancing SAC conventional and other strategic bomber operations through the development of a strategic capability. Specifically, Armstrong Laboratory scientists are interested in determining the effectiveness and limits of SPI through flight simulation experimentation. Additional objectives will include investigating system performance requirements for SPI, operator design considerations, and control/display parameters.

(U) MISSION OVERVIEW

(U) In order to evaluate the SPI concept, a railyard attack mission will be presented to you. The purpose of the railyard attack mission is to destroy stationary rolling stock, primarily boxcars, flatbed cars and locomotives. Three B-52 aircraft will fly the mission in close trail, each aircraft with a predesignated Desired Mean Point of Impact (DMPI) in the target area.

(U) Throughout the simulated mission, SPI will provide you with simulated visual imagery of the target area (i.e., the railyard). This imagery will be presented to you via a CRT display. You will be asked to review/evaluate this imagery and then make certain decisions regarding your targeting preferences.

SCHEDULE

(U) The schedule for the SPI study is depicted in Table 1. Please note that the study will be conducted in half day sessions (morning or afternoon). You will participate in only one of these sessions. Each session is organized into the components described below:

1. <u>Orientation Briefing:</u>	Description of SPI concept Railyard mission briefing
2. <u>Practice Session:</u>	Practice trials conducted on SPI part task device
3. <u>Experiment:</u>	Actual trials conducted and data collected
4. <u>Debriefing:</u>	Structured interview at completion of study

TABLE 1. SPI STUDY SCHEDULE

TIME		SPI ACTIVITY
AM	PM	
0800 - 0830	1300 - 1330	Orientation Briefing
0830 - 0915	1330 - 1415	Practice Session
0915 - 1015	1415 - 1515	Experiment - Part I
1015 - 1030	1515 - 1530	Break
1030 - 1115	1530 - 1615	Debriefing

APPENDIX B
INSTRUCTIONS FOR SPI EXPERIMENT

INSTRUCTIONS FOR SPI EXPERIMENT

Thus far, you have been given a mailer to read that describes the concept of SPI, the objectives of the study, and the simulated mission that will be used for the study. Also you have been given a briefing by Col Marshak. Contained in this briefing was a description of the development process that was followed for SPI, a detailed description of the SPI concept, and a briefing of the railyard mission.

Now I would like to describe the SPI experiment, the materials or tools you will be using, and specific procedures that you will be following.

EXPERIMENT DESCRIPTION

During the experiment, you will be presented with SPI imagery of the target area; in this experiment the target area will always be of a railyard. As you may recall, the purpose of this railyard attack is destroy stationary rolling stock, primarily boxcars, flatbed cars and tankers. The precise positioning of the rolling stock will not be known to you prior to viewing the imagery. Current tactics would divide this target area into four areas for a bomb run, with the centerpoint of each area called a Desired Mean Point of Impact or DMPI.

Let's take a moment and look at two photographs of the railyard that will be used for this experiment. The four DMPIs are identified as 81, 51, 71, and 61. These four DMPIs will remain the same throughout the experiment. Now observe that in these two photographs boxcars and flatbeds have been placed in each of the four DMPIs (point out cars). The placement of the cars will change throughout the trials and you will be asked to make decisions about your targeting preference based on their placement as well as the concentration of cars in each DMPI. Therefore, it is very important for you to be able to identify the quantity of cars in each DMPI. In this particular picture you will notice there is a fairly high concentration of cars in DMPIs 81 and 61 and less cars in DMPIs 51 and 71. Therefore, your targeting decision for this railyard configuration might be to attack both DMPIs 81 and 61.

The SPI imagery that you will see will be presented using five different ingress angles (show picture). Prior to each trial, you will be shown a graphic display that will identify the ingress angle that will be used for the upcoming trial. This display will appear on one of the CRTs used during the experiment.

As you can see, the railyard is surrounded by an urban area which contains buildings and roads. The imagery that you will see during each of the trials will begin outside the developed area with a few seconds of forest, will fly over the urban area, then over the railyard or target area, and then end shortly thereafter. You will be viewing approximately 25-30 seconds of continuous imagery for each passover.

Your job will be to evaluate the SPI imagery displayed during each trial and then make certain judgements regarding your targeting preference. Now let's talk about the specific kinds of decisions you will be making. As Col Marshak stated in the tape you saw earlier, you are flying in a cell of three B-52 aircrafts. You are the lead aircraft and therefore are reponsible for executing the attack plan for the cell. Now under normal circumstances, you would execute a pre-planned attack plan that had been identified for you. But now that you have this new capability, that is SPI, you have some additional options. As you recall, SPI provides you with an advanced look at the target area. Based on this advanced look, you may wish to modify or alter your weapon delivery plan to improve weapon lethality.

During this experiment, you will be presented with several different railyard configurations. Based on these configurations, you will have the option of executing one of 11 plans. Each plan represents a unique attack plan for the railyard. Which plan you choose to execute will be based on your evaluation of the target area and how the cars, flatbeds, and tankers are configured. Now let's take a few moments and review the 11 plans that are available to you. (Review 11 SPI Railyard Configurations. Also use SPI Mission Timeline) A simplified version of the plans will be provided to you during the experiment. This job aid provides you with a picture of the railyard configuration, the entry you would make at the keyboard that corresponds to the DMPI you would bomb, and the plan you would implement.

Now let's talk specifically about the sequence of events for each trial, the displays you will see, and controls you will use to make your inputs. (This part will be conducted at the part task device)

1. Start of Trial or Run At the start of each trial, a graphic will be presented to you identifying the ingress angle for the upcoming run. This will be shown on the PPD. On the SPI Display, a "HIT ANY KEY" prompt will be presented. In order to start the trial, you will press any key.

2. Simulated SPI Imagery Collection Next the real-time SPI imagery will be presented on the SPI Imagery Display, starting with the forest area and ending just past the target area. As I mentioned previously, this imagery will be displayed for approximately 25-30 seconds. During this time, the PPD will present mission critical data. All of these data are displayed at the top of the screen and will be static except the TTG data. The TTG will begin at 2:00 minutes and run till the end of the trial. As you become more proficient, you will use the TTG as an indicator as to whether you have an adequate amount of time to complete your required actions or whether you need to speed up in order to complete your inputs before the end of the trial. In the bottom right hand corner of the screen, mode of operation information is displayed. While the real-time SPI imagery is being displayed, the "SPI RECORDING" mode message will be displayed.

There are two controls that can be used by you during this part of the trial. These controls are the (MARK) key and the (<--) key. (Point out the (MARK) key and the (<--) key) The purpose of the (MARK) key is to designate a particular frame of interest that you would like to review once the real time imagery has been completed. Typically, you will want to use this control to mark a certain frame or area over the target area where you feel you had a particularly good view of the how the railyard is set up. The computer will keep track of only 1 mark per trial. Therefore, if you press the (MARK) key more than once during a given trial, the computer will keep track of your last (MARK) selection. The other key you can use during the imagery collection is the (<--) key. The (<--) key has a dual function during this part of the trial. When you depress the (<--) key, the display of real time imagery stops. This "new end" cannot be changed and any further viewing of the imagery is disallowed beyond this point. Therefore you

must be very careful not to use this key before you have had an opportunity to view all the important/relevant imagery. The second function this key provides is that when depressed, the imagery "REWIND" mode will be activated. The "REWIND" mode message will appear in the bottom right hand corner of the PPD. You will quickly be returned to the "MARK" frame you selected. If you did not use the (MARK) key, you will be returned to the beginning of the SPI imagery. Once the beginning of the SPI imagery or the "MARK" frame has been reached, the mode message will change from "REWIND" to "READY."

3. SPI Imagery Replay Replaying the SPI imagery is optional and is activated at your discretion. There are three controls that are available to you during the "PLAYBACK" mode of the trial. These controls are the (<--) key, the (-->) key, and the (STOP) key. (Point out the (<--) key, the (-->) key, and the (STOP) key). The (<--) and (-->) keys allow you to move forward and backward through the imagery and provide you with an opportunity to look closely at the target area. These keys operate almost like a toggle switch. The (STOP) key is used to freeze or stop the imagery at a particular point of interest. During this part of the trial, the "PLAYBACK" mode message will be displayed in the bottom right hand corner of the PPD. Once again, as in the earlier modes, you'll want to observe the TTG periodically to make sure you aren't running out of time.

4. Select Plan Once you have viewed/reviewed the SPI imagery to your satisfaction, it is time to select a plan based on the railyard configuration that you saw. During this part of the trial you will use the "FLYTO" key, the keys on the number pad, and the (ENTER) key. Here are the steps you would follow:

a. Decide which railyard configuration is represented during the trial. The 11 available railyard configurations are shown on your job aid.

b. Select the lead aircraft entry associated with the railyard configuration. This number is also shown on your job aid. You select the entry by first depressing the (FLYTO) key, entering the two digit number, and depressing the (ENTER) key. Once you have depressed the (FLYTO) key, your input will be displayed in the bottom left corner of the PPD. If you should make a mistake

when entering the two digit number, depress the (<--) key and this will erase/clear your input and allow you to reenter the number again.

c. Select the plan associated with the configuration and the lead aircraft entry. The plan is shown on your job aid. A menu of the available plans will be displayed to you on the PPD. Enter the number associated with the plan of your choice and depress the (ENTER) key. Once again, if you should make a mistake when entering the two digit number associated with the plan, depress the (<--) key and this will erase/clear your input and allow you to reenter the number again.

APPENDIX C
STRUCTURED DEBRIEF QUESTIONNAIRE

STRUCTURED DEBRIEF QUESTIONNAIRE
SPI EXPERIMENT

SUBJECT ID: ______________________ DATE: ______________

The table presented below shows at a global level of detail the mission areas where SPI may be used. The purpose of this table is to orient you to the types of questions that we will be asking.

I.	II.	III.	IV.	V.
MISSION PLANNING	OCCUPANCY CHECK	REPLANNING	WEAPONS DELIVERY	BOMB DAMAGE ASSESSMENT

The SPI experiment focused on Occupancy Check (target acquisition) and Mission Replanning. For the development of this simulation, we developed a notional mission plan with associated tactics. This debrief will present questions regarding:

SECTION I: Decision Making Strategy for Evaluating Imagery
Controls and Displays (C&D)

In this section we will obtain your comments regarding the decision making process that you followed during the experiment. In addition we are interested in your strategies for using the controls and displays.

SECTION II: Imagery Evaluation

This section focuses on the imagery used for the SPI study. We are interested in your comments regarding our imagery and suggestions for improvement.

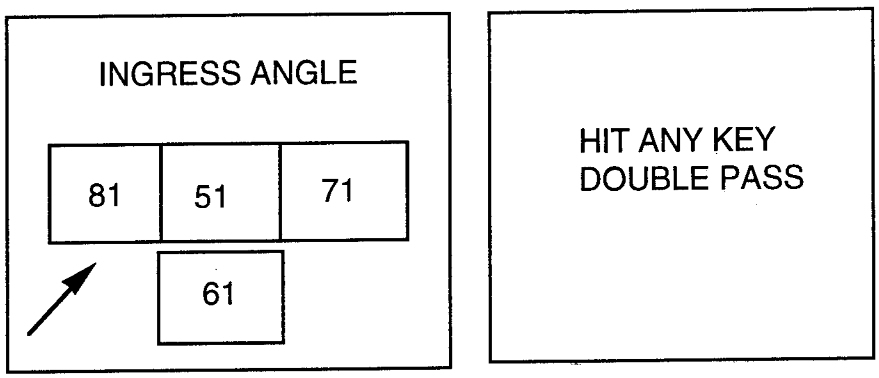
SECTION III: SPI Concepts and Tactics

We would like your comments and suggestions regarding the mission that was developed for this simulation. We would like to explore alternative mission concepts and tactics.

SECTION I

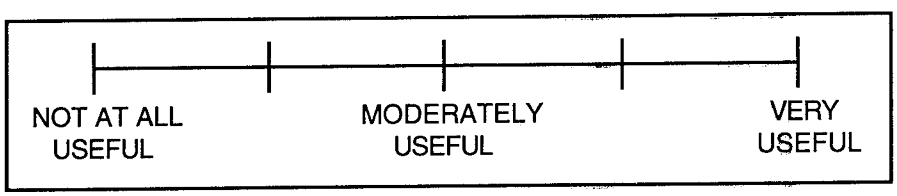
DECISION MAKING STRATEGY FOR EVALUATING IMAGERY CONTROLS AND DISPLAYS

The following section contains questions regarding the decision making strategy you used to evaluate the SPI imagery. This section also contains questions about the SPI Part-Task Device controls and displays that were available to you during the experiment.

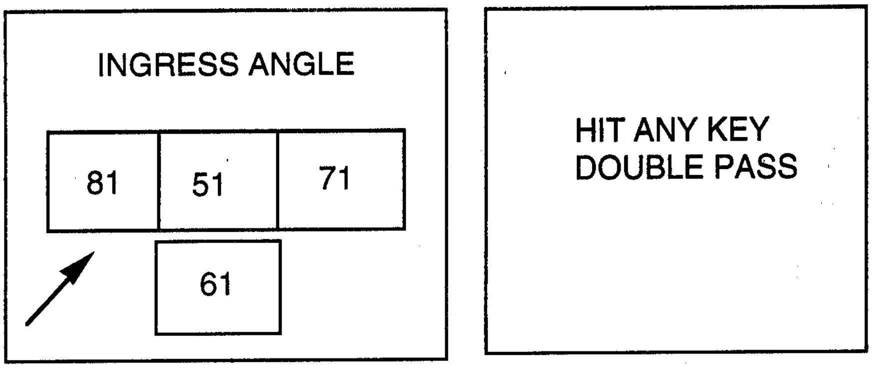


SPI PART-TASK DEVICE
PRE-TRIAL CONTROLS AND DISPLAYS

1a. Did you find the ingress angle display to be useful?

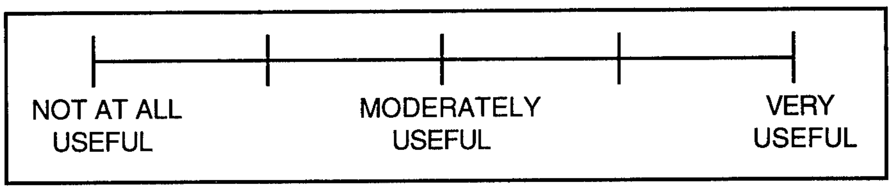


1b. Any suggestions for improvement?



SPI PART-TASK DEVICE
PRE-TRIAL CONTROLS AND DISPLAYS

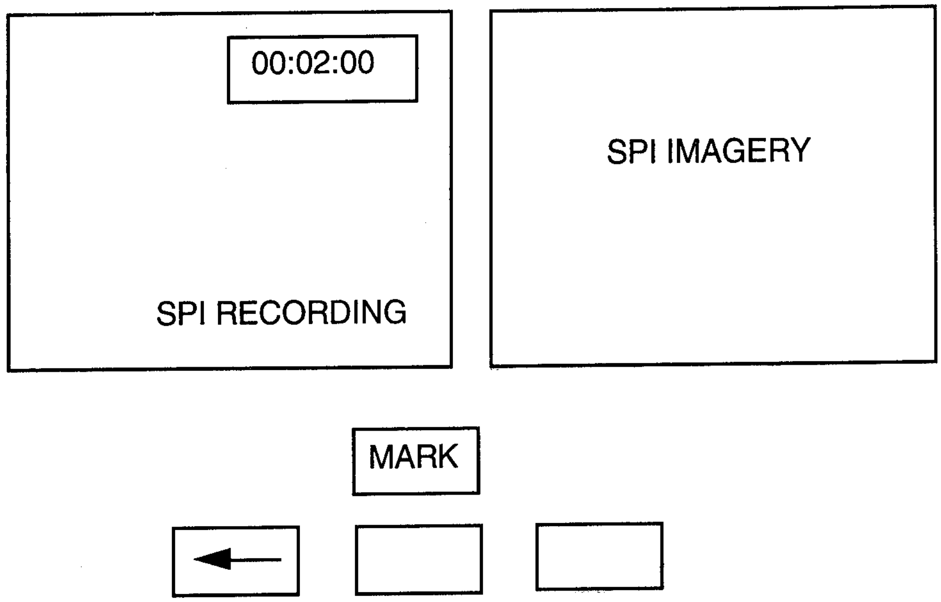
1c. Was the "DOUBLE PASS" prompt useful?



1d. Did the "DOUBLE PASS" prompt affect your strategy for the upcoming trial?

YES ____ NO ____

If yes, how?



SPI PART-TASK DEVICE
"SPI RECORDING" MODE CONTROLS AND DISPLAYS

2a. Did you use the TTG data?

YES ____ NO ____

If yes, how?

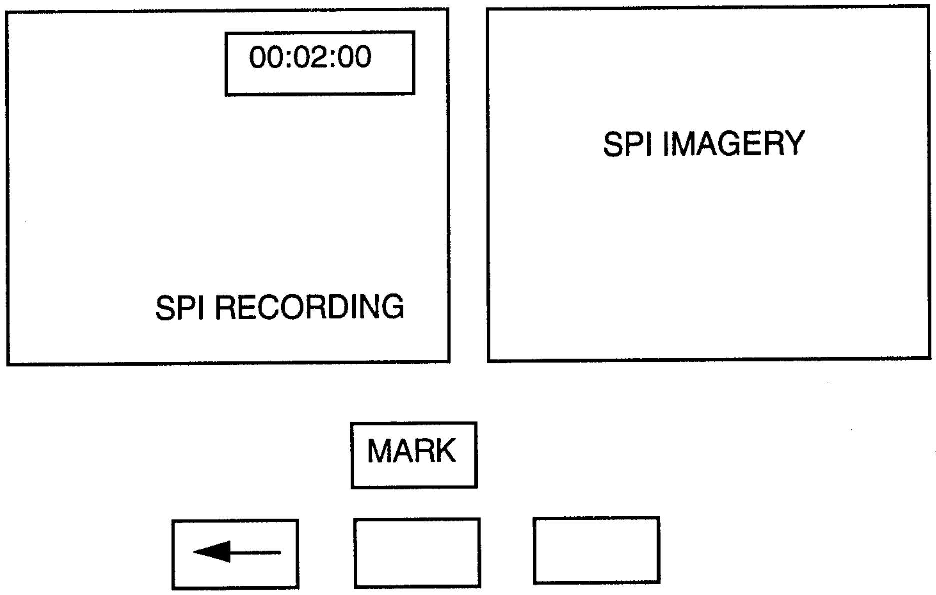
2b. Did you have an adequate amount of time to complete each trial?

YES ______ NO _______

2c. Did you refer to the "SPI RECORDING" prompt during the trial?

YES ____ NO ____

If yes, how did you use this prompt?



SPI PART-TASK DEVICE
"SPI RECORDING" MODE CONTROLS AND DISPLAYS

2d. Did you use the (MARK) key?

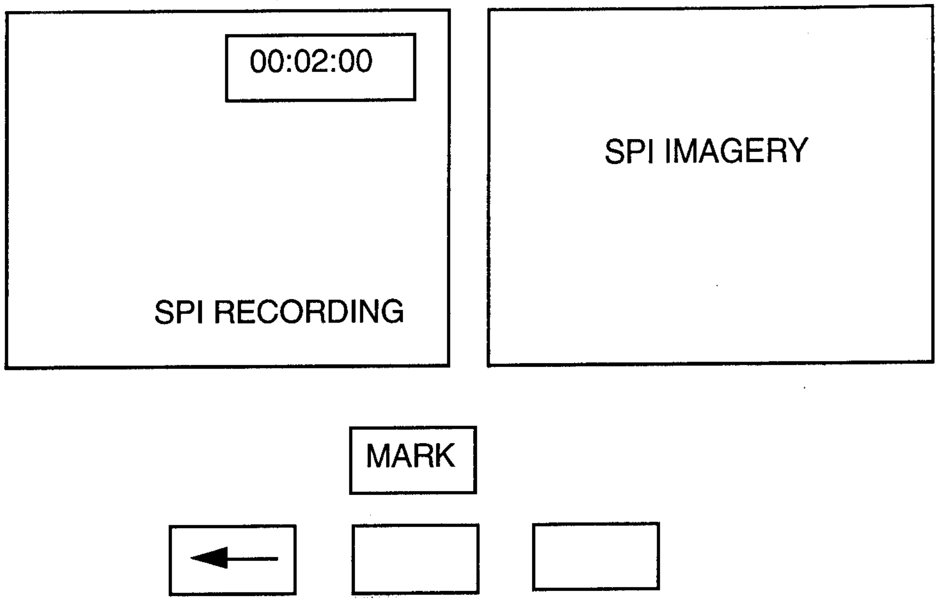
YES ____ NO ____

If yes, what was your strategy for its use?

2e. In an operational setting would you like to see a (MARK) capability?

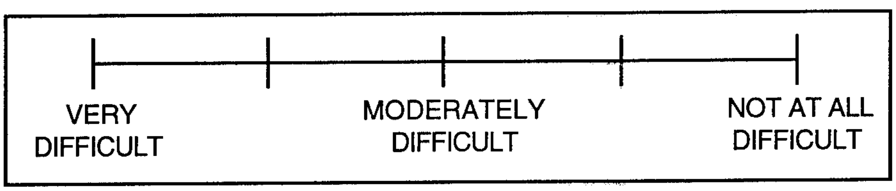
YES ____ NO ____

If yes, would you implement it in a similar fashion as was used in this study or can you see a better way?

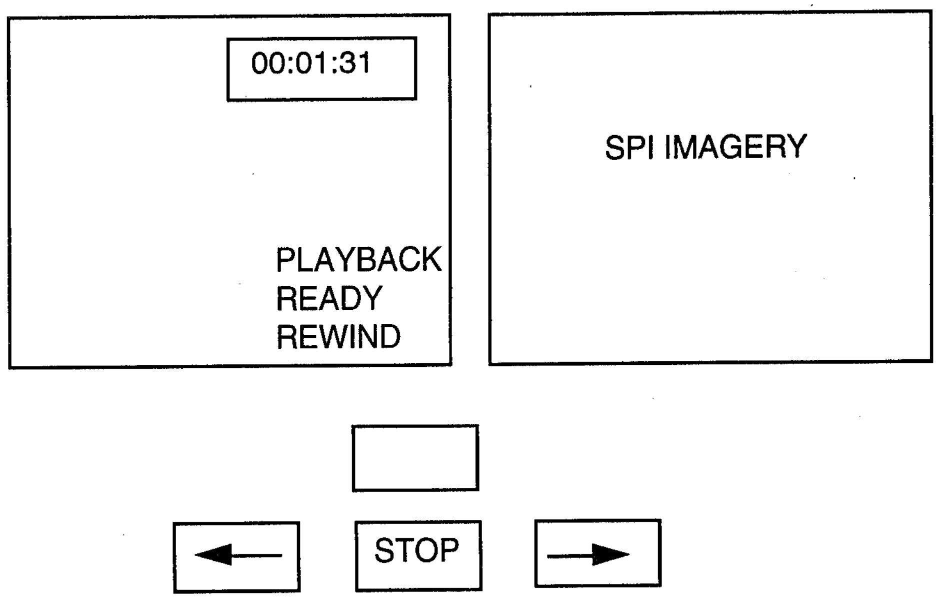


SPI PART-TASK DEVICE
"SPI RECORDING" MODE CONTROLS AND DISPLAYS

2f. As you know, the (<--) key acts as a dual function key in that it ends the "SPI RECORDING" mode and at the same time takes you back to the frame that you marked. Was this dual function capability (in terms of its usability):



2g. What was your strategy for using the (<--) key?



SPI PART-TASK DEVICE
"SPI PLAYBACK" MODE CONTROLS AND DISPLAYS

3a. Did you use or continue to use the "TTG" data during the "PLAYBACK" mode?

YES ____ NO ____

If yes, how?

3b. Did you refer to the "PLAYBACK", "READY", and "REWIND" prompt during this part of the trial?

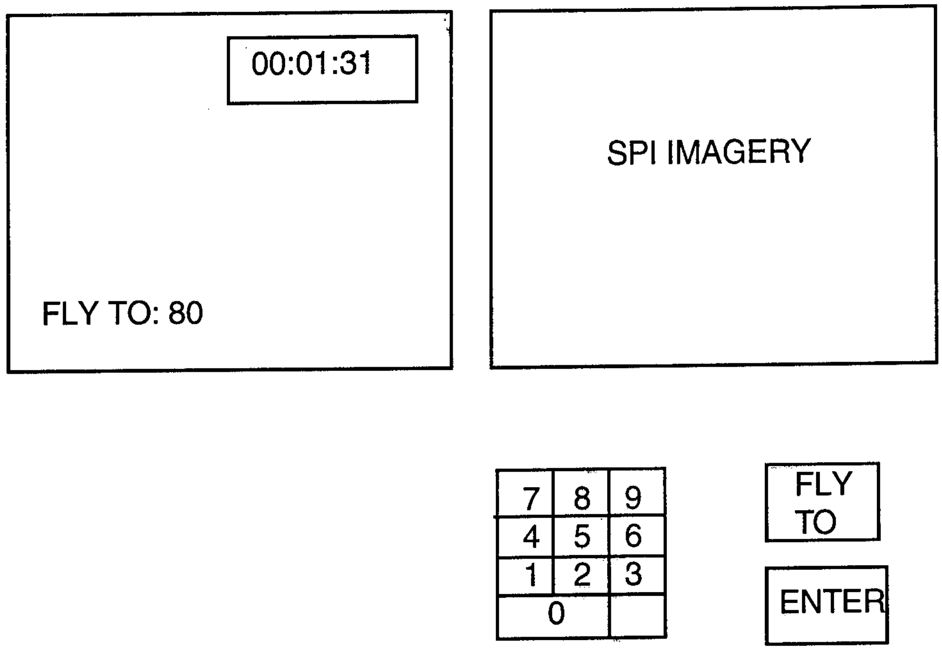
YES ____ NO ____

If yes, how did you use this prompt?

3c. What strategy did you use regarding the use of the (<--) key, the (STOP) key, and the (-->) key?

Any suggestions for improvement?

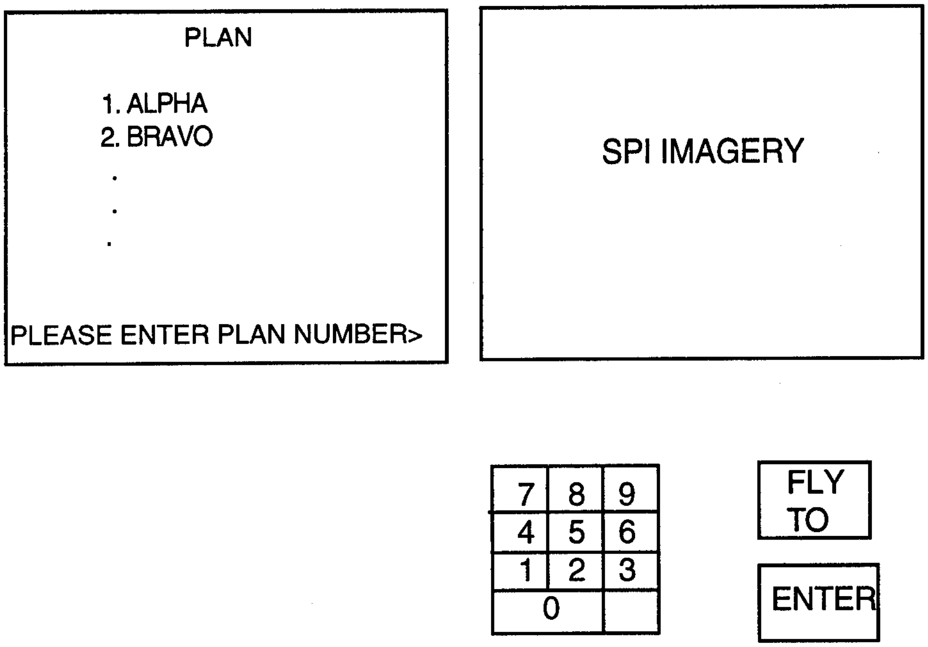
3d. In an operational setting would you like to see the (<--) key, the (STOP) key, and the (-->) key implemented in a similar way?



SPI PART-TASK DEVICE
"INPUT FLYTO" MODE CONTROLS AND DISPLAYS

4a. What did you think of the procedure used to input the the "FLYTO"?

4b. How would this procedure be implemented in an operational environment?



SPI PART-TASK DEVICE
"INPUT PLAN" MODE CONTROLS AND DISPLAYS

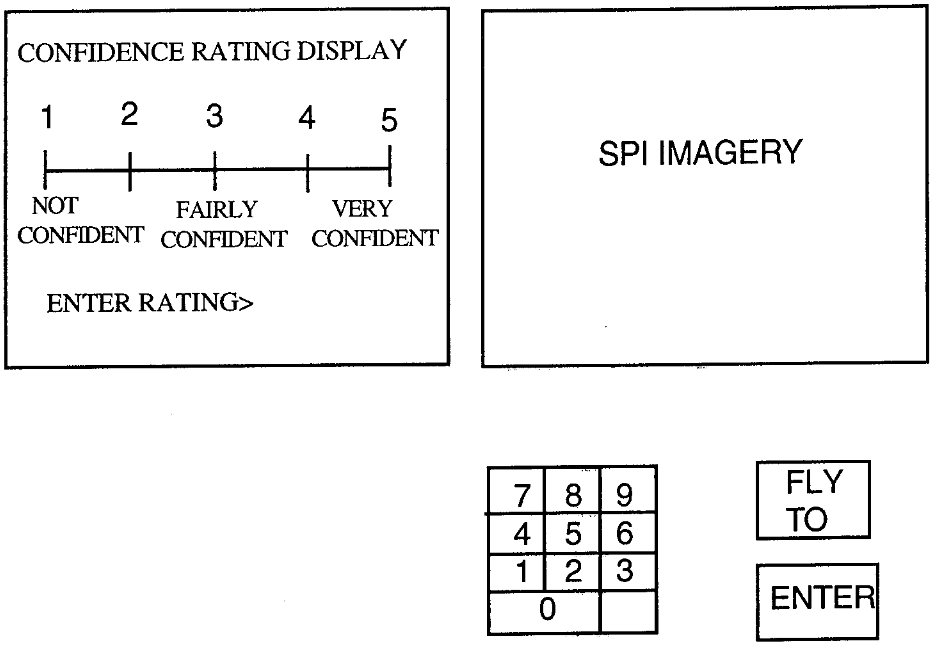
5a. What did you think of the procedure used to input the the Plan?

5b What do you think of the Plan concept, i.e., inputting a attack plan for the entire cell?

5c. Is the Plan concept something that could be implemented in an operational setting?

YES ____ NO ____

If yes, how?

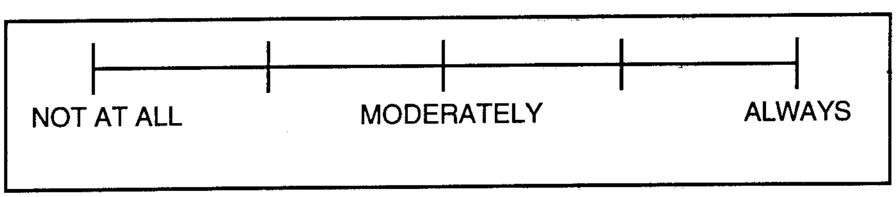


SPI PART-TASK DEVICE
"INPUT CONFIDENCE RATING" MODE CONTROLS AND DISPLAYS

6a. What did you think of the procedure used to input confidence ratings?

6b. What was your strategy for selecting a given confidence rating?

6c. How did the double pass affect your degree of confidence?



6d. How did single and dual pass affect your accuracy? Did you usually change your mind based on the second pass or did it reinforce your original decision?

SECTION II
IMAGERY EVALUATION

General Imagery Questions

1. Did you think the SPI imagery was realistic?

   YES ___ NO ___

   If not, what specific criticisms do you have?

2. Did the SPI imagery provide you with the necessary information to make a targeting decision?

3. Did the imagery mislead you in any way?

4. The SPI imagery playback/review capability could be implemented using one of two modes: a continuous transmission or a burst transmission. A burst transmission would result in you viewing snap-shots rather than continuous imagery. Which would you prefer?

   Continuous ____ Snap-Shot ____

   Why?

Specific Imagery Evaluation

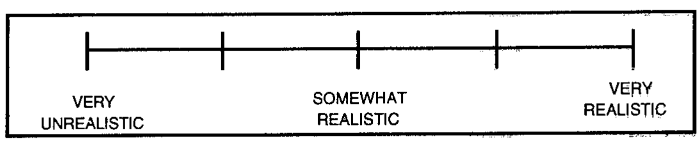
The following section contains questions regarding various aspects of the SPI imagery. You will first be asked to rate the different aspects of the imagery and then provide comments.

For each of the following, we would like you to rate the "realism" of our imagery. When we evaluate imagery realism the following factors are generally considered:

1. Brightness
2. Color
3. Sharpness
4. Level of Detail
5. Clarity
6. Dynamic Aspects such as Movement

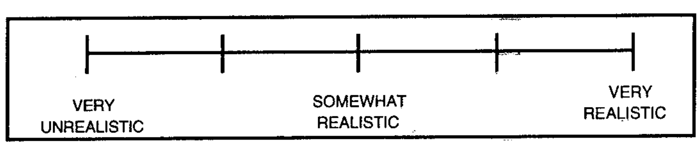
Consider the above factors, and others that you may think of in making your ratings. After you make your rating, indicate the factors that **you** considered.

1. Forest Area



What factors did you consider?

2. Urban Area including buildings, roads, and other landmarks



What factors did you consider?

3. Target Area (Railyard)

VERY UNREALISTIC | SOMEWHAT REALISTIC | VERY REALISTIC

What factors did you consider?

a. Reference points or landmarks

VERY UNREALISTIC | SOMEWHAT REALISTIC | VERY REALISTIC

What factors did you consider?

b. DMPI Areas

VERY UNREALISTIC | SOMEWHAT REALISTIC | VERY REALISTIC

What factors did you consider?

c. Targets (Railcars, flatbeds, and locomotives)

VERY UNREALISTIC | SOMEWHAT REALISTIC | VERY REALISTIC

What factors did you consider?

SECTION III
SPI CONCEPT AND TACTICS

This SPI experiment used the mission route shown on the next page. The mission was developed to exercise the SPI concept. We understand that our mission objectives and specific targeting of the railyard area are not totally realistic. This is reflective of our imagery and imagery manipulation limitations.

Your answers to the following questions will assist us in specifying the limitations of the current mission and in developing a more realistic mission scenario for future studies (simulations or flight tests).

1. Do you think that the limitations in the current mission restrict our ability to demonstrate the effectiveness of an SPI concept?

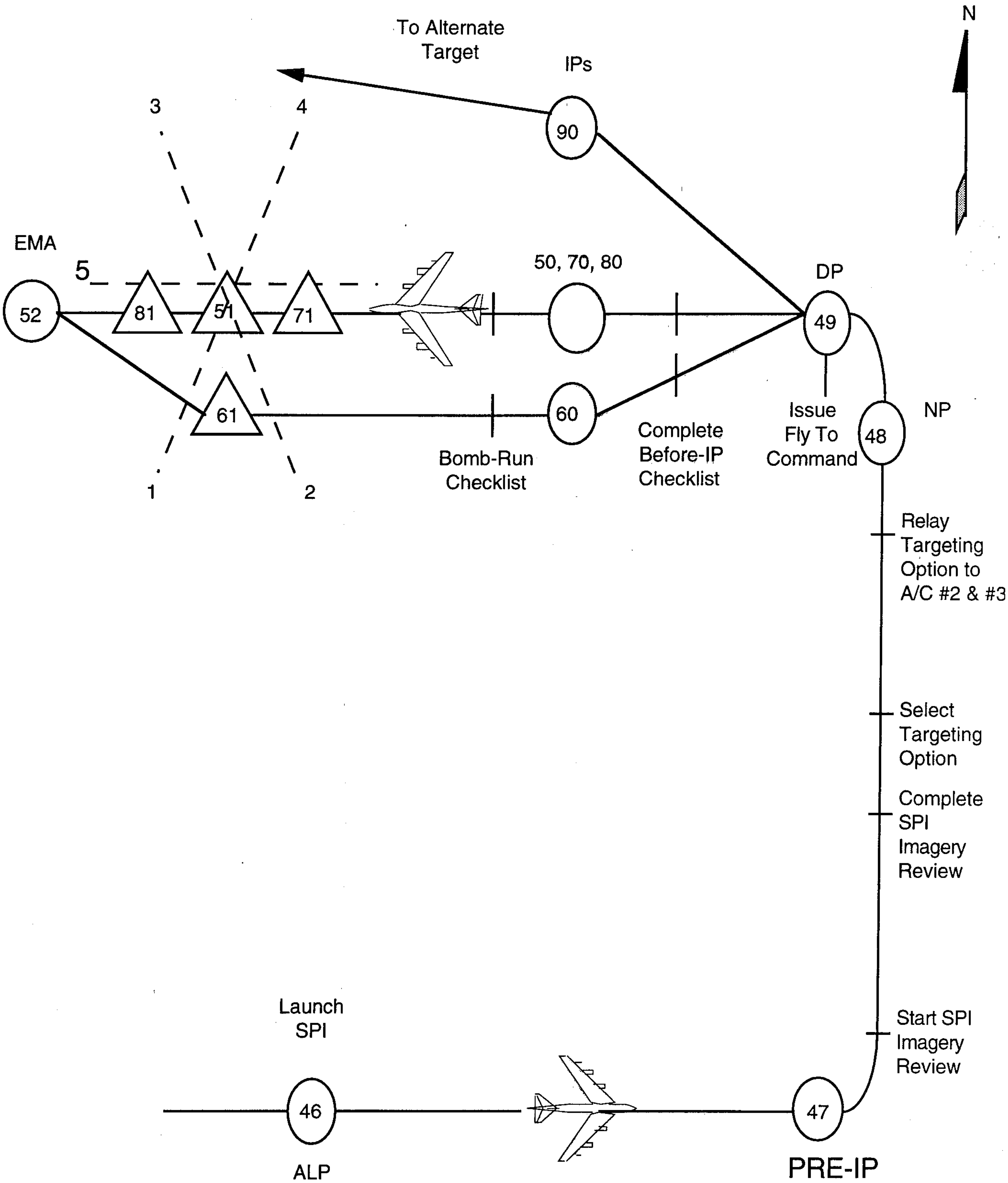
   YES ___ NO ___

   Why?

2. What are your suggestions for improving the realism of the SPI railyard mission. Please keep in mind that we want to use a mission that demonstrates the potential of SPI (You can mark your comments on the graphic of the mission).

3. Do you have any suggestions for using SPI for BDA?

4. For what other types of missions do you think the SPI would result in an increase in mission success?



OVERVIEW OF THE SPI MISSION PROFILE

APPENDIX D
QUESTIONNAIRE AND DEBRIEF RESULTS

Decision Making and Controls and Displays

1a. Did you find the ingress angle display to be useful?

1	2	3	4	5
NOT AT ALL USEFUL		MODERATELY USEFUL		VERY USEFUL

Average =	4.54	Standard Deviation (SD) =	0.80
Mode =	5.00	Range =	2.75

1b. Any suggestions for improvement?

- Would like to see ingress angle left up throughout the trial.
- On double passes, display both passes on one ingress angle display. Will aid in what operator expects to see on second pass.
- Rotate the picture 45 degrees on the paper (so arrow is always up)
- Fine as is.
- Would be nice to have access throughout trial - used picture of railyard because sometimes forgot ingress angle.

1c. Was the "DOUBLE PASS" prompt useful?

1	2	3	4	5
NOT AT ALL USEFUL		MODERATELY USEFUL		VERY USEFUL

Average =	4.23	Standard Deviation (SD) =	0.89
Mode =	5.00	Range =	2.00

1d. Did the "DOUBLE PASS" prompt affect your strategy for the upcoming trial?

	Frequency
YES	6
NO	6

If yes, how?

- It bought time to evaluate and rethink the first pass and validate the decision on the second pass.
- With the double pass I only recorded the section I was interested in on the second pass -- e.g., on the first pass I formed my assessment with an area in question. On the second pass I only recorded that area I had in question.
- It would be better if no decision had to be made until after viewing the second pass.
- Establishing expectations on what I might see on second pass. Establishing "pointer system" to questionable target areas so I could identify easier.
- Prepared me to concentrate on questionable DMPIs on the following pass.
- Sometimes didn't remember which was DOUBLE PASS. Reserve judgement, more confident because of second pass.
- If questionable area in first pass, would focus on questionable area immediately in second pass - also used to reinforce first decision.

2a. Did you use the TTG data?

	Frequency
YES	6
NO	6

If yes, how?

- Pacing for decision making on a more difficult run.
- To monitor time. Started disregarding after realized had adequate time.
- Pacing to decision.
- Deciding how long to wait to analyze data.
- To determine time remaining to make decision.

2b. Did you have an adequate amount of time to complete each trial?

	Frequency
YES	9
NO	3

2c. Did you refer to the "SPI RECORDING" prompt during the trial?

	Frequency
YES	2
NO	10

If yes, how did you use this prompt?

- To know when I could go forward or backward after rewinding to mark.
- Referred to it but didn't use it other than nice for reference. Should be in aircraft because of many distractions.

2d. Did you use the (MARK) key?

	Frequency
YES	12
NO	0

If yes, what was your strategy for its use?

- Mark as soon as the target area came on screen. Mark when target area left screen.
- Used so could refer back to imagery. Usually marked in center of railyard.
- On a single pass I would mark the frame that gave me the best overall view. On a double pass I would get the best overall view on the first and mark the area in question for a quicker review.
- Used it to mark the point where all useful video had passed. This allowed use of forward/reverse without having to wait at the mark.
- Identify target area as far out as possible.
- To freeze recording at a key evaluation point.
- To eliminate extraneous video -- i.e., cut to the chase.
- At point where could see the earliest possible view marked - reduced amount of replay.
- To review targets.
- Marked optimum viewing angle.
- To return to the beginning of the target area to review it.
- To review area.

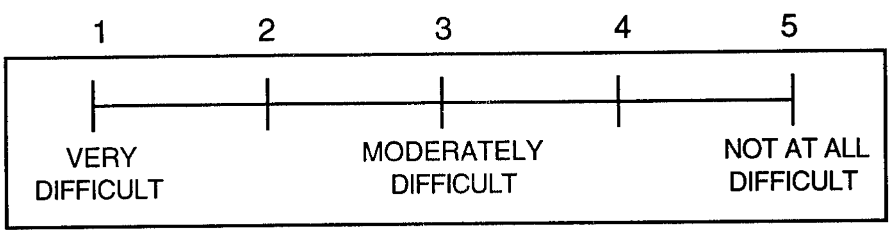
2e. In an operational setting would you like to see a (MARK) capability?

	Frequency
YES	12
NO	0

If yes, would you implement it in a similar fashion as was used in this study or can you see a better way?

- No - similar fashion.
- Same as is. Would like capability to review both mark areas for each pass that was part of a double pass.
- Better clarity in freeze. Frame numbers. Ability to rotate image. Better resolution. Use color.
- I would use it the same way until a better one is invented.
- Would like to see capability to mark up to three frames. Any more may lead to confusion and indecision.
- Use like freeze frame on OAS.
- Fine as is.
- Same way - fine as is.
- Good as is.
- Fine as is.
- Similar way. It was quick and efficient.

2f. As you know, the (<--   ) key acts as a dual function key in that it ends the "SPI RECORDING" mode and at the same time takes you back to the frame that you marked. Was this dual function capability (in terms of its usability):



Average =	4.31	Standard Deviation (SD) =	0.93
Mode =	5.00	Range =	3.00

2g. What was your strategy for using the (<--) key?

- None
- Reposition back to mark. Would prefer having two function keys rather than a dual function key.
- End recording after the area of interest was past. Rewind when area in question passed.
- Viewing on reverse only.
- Finally figured out that you could use both <-- and --> to have continuous display, without stopping imagery.
- Dual function keys are a problem when under stress. It would seem better to use two keys for this function. That is, one for stopping SPI recording and one for going back to mark frame.
- Again, to eliminate excess video.
- Let imagery go few frames past area of interest then hit <-- key.

- Review as many times as required. Most times could not go back before mark point. Forgot to tell about inactive during rewind.
- As soon as past target area, hit left arrow to stop recording.
- To return to the beginning of the target area.
- Just as described in dual mode. I used it to mark the search area and to terminate SPI recording past search area.

3a. Did you use or continue to use the "TTG" data during the "PLAYBACK" mode?

	Frequency
YES	6
NO	6

If yes, how?

- Pacing - I think you will find all B-52 NAVs use TTG for timing and pacing, that is how we are trained.
- In the beginning, then disregarded as became more proficient.
- Pacing.
- To determine the time remaining to reach a targeting decision. (At 30 sec. needed to make enter decision).
- Make sure had adequate time to complete trial.
- Referenced when done recording; periodically during replay referred to it, at 30 sec. go over one more time and then input.

3b. Did you refer to the "PLAYBACK", "READY", and "REWIND" prompt during this part of the trial?

	Frequency
YES	6
NO	4
NO ANSWER	2

If yes, how did you use this prompt?

- I used the ready and rewind to tell me when I could playback and that my request for rewind was working.
- Primarily looking for the switch from rewind to ready so I could begin playback -- used to minimize wasting time.
- Would be helpful if it were displayed on the imagery screen.
- Ready and rewind - to make sure it was activated.
- As an indication of when I could press the control keys.
- To hit forward --> once run was complete.

3c. What strategy did you use regarding the use of the (<--) key, the (STOP) key, and the (-->) key?

- Never used (<--) key. Used stop to stop mark then (-->) for replay.
- Move back to mark, went forward and backwards to get clear image. Might not have used if image had been clear -- i.e., didn't use stop because of image jitter.
- After the recording was made (from "mark" to "stop") I used the rewind & play (-->) keys repeatedly to review the area.
- Only to view film forward and backward.
- Tried to avoid stop. Tended to blur imagery. Used <-- and --> keys for continuous replay, forward-reverse.
- Used from mark prompt forward. Also, key and stop to advance the picture.
- Used stop to advance one frame at a time. Didn't toggle - left only for back to mark right to overfly.
- Used them all, alternating.
- From mark, used --> key, used stop to count cars, then <-- key to back to mark. Didn't use stop very much because of jitter.
- To freeze frame and to "walk" the video frame by frame through the run.
- To review information. Stop key used only to attempt to verify images.

Any suggestions for improvement?

- Yes. Allow (<--) key to back up (rewind tape slowly as opposed to going back to frame 1).
- Clearer image on mark frame.
- None needed.
- During replay once final <-- frame was reached automatically go back to mark. Could imagery be slowed down during replay? Or best alternative improve resolution during freeze capability.
- Enhance the picture during the freeze frame.
- None in this mode.

3d. In an operational setting would you like to see the (<--) key, the (STOP) key, and the (-->) key implemented in a similar way?

- Yes. However, allow (<--) key to back up (rewind tape slowly as opposed to going back to frame 1).
- Didn't like double key for (<--) key clear image or stop.
- No. In this setting we were only looking at one area & our set of images. In the field you could have the drone looking at multiple areas on our pass and a single set of keys may result in some confusion.
- Yes.
- Forward and reverse play features might be better than mark key.

- Yes, except for separate key to stop SPI recording to prevent mistakes.
- Same as is.
- Same as is.
- Would be nice to be able to scroll back and forth, no key pressed would stop jumping back to mark separate key.
- Yes.
- Yes.

4a. What did you think of the procedure used to input the the "FLYTO"?

- Normal -- but should use OAS IKB. NAVs will integrate procedure into 60TG technique (i.e., 60TG - pilot maintain HDG, disregard FCI, etc.).
- Ok
- Fine.
- No problem in use. All B-52 & B-1B operators are familiar with its function.
- Fine.
- Fine as is.
- Fine.
- Same as is - alot like OAS.
- Fine as is.
- OK.

4b. How would this procedure be implemented in an operational environment?

- Similar to our procedure.
- Yes, at the turn point, at the IP but not in the segment we were on when the decisions were made.
- Same way, with lead relaying attack plan (A,B,C, etc.) to trailers.
- Flying to different IPs in order to establish various angles of attack and possibly threat avoidance.
- Same way.
- Same way -- existing procedure.
- Realistic as is.
- Same as is.
- Fine as is.
- The same way.
- Depending on time constraints between prime and alternate target. I think this could be effectively and easily implemented.

5a. What did you think of the procedure used to input the the Plan?

- Confusing - could mislead operator if he feels he sees something not on the plan.

- Plan should have same designation as screen designation.
- OK for the experiment.
- Fine.
- A pre-established plan of attack aids operator's decision making. All he has to do is identify targets and not worry about how he will attack.
- Fine.
- Input the alpha characters indicated by the plan.
- I didn't like it. Put "alpha, bravo, .." first, then number choice.
- Fine as is.
- OK.
- Satisfactory. I misstruck a key occasionally while looking up the plan with corresponding number.

5b What do you think of the Plan concept, i.e., inputting an attack plan for the entire cell?

- Too complicated - just call it out on radio.
- Adequate.
- It's workable. Provided you could have operational security.
- Good.
- Think its great. Should be a staff function, not left up to crewmembers.
- Fine.
- Good idea.
- Good idea.
- Makes sense because usually best crew is in lead of cell.
- Good plan in that it was simple.
- Okay, but with modifications to make display easier to read.

5c. Is the Plan concept something that could be implemented in an operational setting?

	Frequency
YES	11
NO	1

If yes, how?

- The idea that each bomber in the cell would strike a specific box depending on the plan is workable. The problem you face is bomber spacing and adjusting that for each variation (fatricide). It is reasonable to do that in mission planning. The weakest link is the communication just prior to the bomb run. How do you get adequate communication (reliable, secure) without compromising your security? Unless each bomber is on the same plan you could either destroy a following bomber or destroy his bombs making his sortie useless. Too much communication could jeopardize the entire cell.

- Same way, with lead relaying attack plan (A,B,C, etc.) to trailers. Also, all options should be included, there were a few missing (i.e., bombing 51, 71 & 81).
- Yes, but probably difficult with RTs. Plan should incorporate a "black line". Cells then fly "finger tip formations". Variations of the plan would be to move "black line" N-S-E or by a pre-defined distance. Once targets visually acquired, aircrew makes last inputs, close to bomb release, by flying over target. Incorporate NVG for night or IFR conditions.
- Pre-planned mission scenarios.
- Same way.
- Liked the idea. Do all aircraft see SPI imagery? Should because what happens if lead aircraft has maintenance problems and doesn't go in.
- The same way it was done here except that all target combinations would need to be provided.
- Using OAS display for weapons data?

6b. What was your strategy for selecting a given confidence rating?

- Read and interpret the scale based on how confident I was with my decision.
- Usually rated high because decision was made (4 or 5).
- Usually had more confidence on the second pass. If I could verify large concentration my confidence was high. If I couldn't decide if there was a large concentration but enough to justify a bomb run my confidence was high.
- I always selected 5 unless there was no plan for the areas I wanted to hit (i.e., 51, 71, 81) and I had to select a lesser choice/plan.
- Speed at which I acquire target area.
- How well I was able to discern imagery.
- Gut feeling as to how readily identifiable the railcars were (Subjective). DMPI 61 sometimes not as confident.
- Didn't use extremes - partly because of imagery but also because of style.
- Starting point, fairly confident but never 100% confident (5). Usually picked 3 or 4, DMPI 61 kept from being 100% confident.
- Never used 1, 2 maybe `15% (when imagery was questionable, i.e., didn't know if enough cars or not) 3&4 used the most.
- No strategy just gut feel.
- Whether I felt I had seen enough of the image to warrant the rating.

6c. How did the double pass affect your degree of confidence?

1	2	3	4	5
NOT AT ALL		MODERATELY		ALWAYS

Average =	3.94	Standard Deviation (SD) =	1.07
Mode =	5.00	Range =	3.00

6d. How did single and dual pass affect your accuracy? Did you usually change your mind based on the second pass or did it reinforce your original decision?

- I found the dual pass much easier because it allowed me more information to validate or change my first impression. More often than naught it validated my decision. Rarely did I change totally. Single Pass - I made my best decision based upon the information I had and went with it. That's the way the bombing business goes.
- If high confidence on first image, reinforced original decision.
- Usually it reinforced.
- Both
- Changed my mind only once, I think. Most of the time it reinforced original decision.
- Changed input if second pass increased confidence.
- Reinforced original decision.
- Mostly reinforced original decision. Rarely changed.
- Usually reinforced it.
- Only changed mind couple of times (low confidence rating on first pass). Most of the time reinforced original decision.
- Usually reinforced it.
- Reinforced decision.

General Imagery Questions

1. Did you think the SPI imagery was realistic?

	Frequency
YES	11
NO	1

If not, what specific criticisms do you have?

- Too much bounce on freeze frame, add this to aircraft movement and there could be a problem.
- Imagery tended to vibrate/become fuzzy when stopped making counting of targets difficult.

- Forest depiction unrealistic. Urban depiction good.
- Jitter in freeze frame capability.
- DMPI 61 difficult - why should cars look different in 61 than other DMPIs - and thus that part looked unrealistic.
- Only screen jitter.
- It was realistic to a degree. In some instances, targets faded out or popped into view as you approached the area. The blurriness of the still picture was very difficult.
- I wanted more control over contrast to fine tune the image.

2. **Did the SPI imagery provide you with the necessary information to make a targeting decision?**

- All 12 subjects stated "Yes" or that "Generally" the imagery provided the necessary information.

3. **Did the imagery mislead you in any way?**

- Yes. DMPI 61 - better control over contrast or brightness would have helped.
- Yes. It is very difficult to separate grey areas. Need better resolution.
- No! Sometimes prompted questions in my mind.
- Without gain or receiver controls hard to tune image.
- Initially the "negative" depiction of DMPI 61 was confusing.
- Angle 5 was misleading if only choice. Because we used other angles was able to do better with angle 5.
- Only on DMPI 61 when wasn't sure what was a car - lighter cars.
- Only on angle 5.
- Occasionally.

4. **The SPI imagery playback/review capability could be implemented using one of two modes: a continuous transmission or a burst transmission. A burst transmission would result in you viewing snap-shots rather than continuous imagery. Which would you prefer?**

	Frequency
CONTINUOUS	9
SNAP-SHOT	3

Why?

- Continuous. It flows much better and gives you a real time data flow much the same way our equipment works -- its what we are used to.
- Continuous. Because received additional cues because of motion.

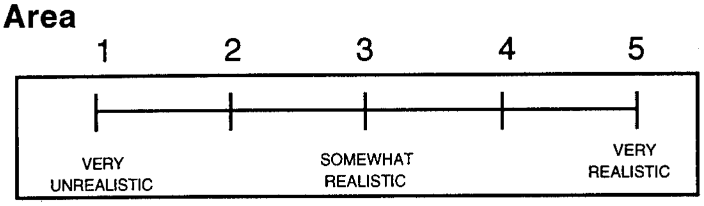
- Snap-Shot. If we could be sure that the images were of the target area a snap shot would be adequate. A continuous display just gives you the option of selecting which frame or frames you select to make your decision. Multiple snap shots would accomplish the same thing. I'm attracted to the idea of having a remote video camera at my control but I don't think it would enhance the mission.
- Continuous. More flexibility, however snap-shot could be used as long as frame overlapped in order to allow reference.
- Continuous. Allows you to anticipate what you should be observing.
- Snap-Shot. If clarity is greater, one good picture is better than continuous data.
- Continuous. As SPI covers the target area, ground images alter in their appearance. A continuous capability allows the operator to pick and choose the best presentation.
- Continuous. With burst you might miss the one frame you need.
- Continuous. Need to see it change - mind needs the motion to properly interpret data.
- Continuous. Because motion allows you to identify cars better.
- Snap-Shot. If it were clear. More time to analyze it.
- Continuous. Shapes change. One shot (Snap) was not enough for me to make a decision with confidence in all cases.

<u>Specific Imagery Evaluation</u>

For each of the following, the RNs rated the "realism" of our imagery. The RNs considered the following factors in their ratings:

1. Brightness
2. Color
3. Sharpness
4. Level of Detail
5. Clarity
6. Dynamic Aspects such as Movement

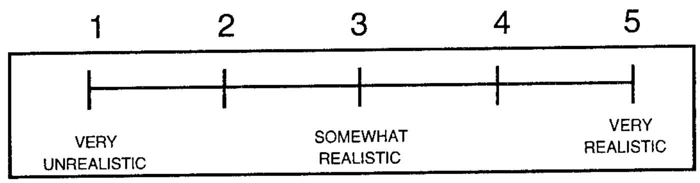
1. Forest Area



Average =	3.38	Standard Deviation (SD) =	1.04
Mode =	3.00	Range =	2.75

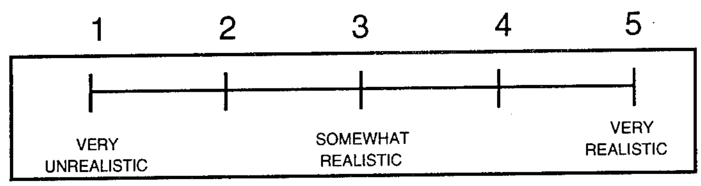
No responses = 2

2. **Urban Area including buildings, roads, and other landmarks**



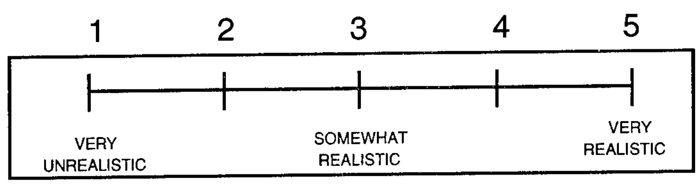
Average =	3.73	Standard Deviation (SD) =	0.62
Mode =	2.00	Range =	1.50

3. **Target Area (Railyard)**



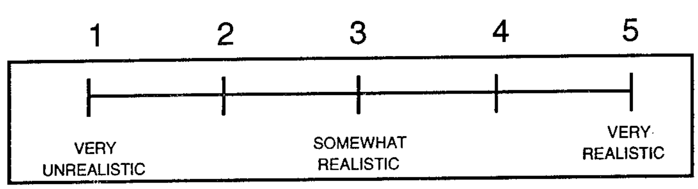
Average =	3.92	Standard Deviation (SD) =	0.53
Mode =	4.00	Range =	1.50

a. **Reference points or landmarks**



Average =	3.61	Standard Deviation (SD) =	0.67
Mode =	3 & 4	Range =	1.25

b. **DMPI Areas**



Average =	3.67	Standard Deviation (SD) =	0.74
Mode =	4.00	Range =	2.25

c. Targets (Railcars, flatbeds, and locomotives)

1	2	3	4	5
VERY UNREALISTIC		SOMEWHAT REALISTIC		VERY REALISTIC

Average =	3.42	Standard Deviation (SD) =	0.67
Mode =	3.00	Range =	2.25

<u>SPI Concepts and Tactics</u>

1. Do you think that the limitations in the current mission restrict our ability to demonstrate the effectiveness of an SPI concept?

	Frequency
YES	0
NO	12

Why?

- As a concept SPI can easily be demonstrated by integrating present software/firmware/hardware into WST.
- I think it demonstrated an ability to gather real time data and use it.
- Time constraint is viable, multiple pass idea is good. Good to have included multiple angles for viewing.
- Would have been more realistic if had craters or other damage on some runs.
- I think the concept is demonstrated effectively with this exercise.
- Double pass and mark overcome the limitations in my opinion.

2. What are your suggestions for improving the realism of the SPI railyard mission. Please keep in mind that we want to use a mission that demonstrates the potential of SPI (You can mark your comments on the graphic of the mission).

- None, this is a good mission. Integration into OAS PTT or sim (WST) would be beneficial also.
- SPI could be alerting enemy that we are coming. Would not fly aircraft on same ingress as SPI. Improve device -- cockpit display.
- Compare other imaging techniques with the visual (i.e., JSTARS type images).
- Include all options for attack plan (i.e., all possible combinations of DMPIs).
- Need to get away from the mindset that bombers fly in trail. Straight IP to target is typically SAC. Look toward short roll-in

bomb runs, cells of bombers abreast, consider frag pattern of MK82.

- I feel the capability is demonstrated.
- What is the spacing between aircraft? Are we a cell? If one goes to alternate, are we in formation? Would like to know time from start of imagery to DP.
- Multiple IP is Okay. This is close to the bomb run (Pre-IP to 48) double amount of time would like to have 6-7 minutes.
- Deciding where DP is is an important operational question.
- Mainly improving the quality of the video so that the confidence factor of the operator would be high.
- Better use of contrast similar to on-board capability.

3. Do you have any suggestions for using SPI for BDA?

- Launch SPI from last aircraft in the cell. This should allow plenty of time for smoke etc. to clear before viewing target area. Beam results back to command post. Don't belabor crews with BDA, let them concentrate on safely egressing the FEBA and returning home safely.
- SPI would be good for BDA but probably not right away because of smoke. Would need time lag to get good imagery.
- The fly over after is adequate. Loiter time is desirable but not necessary.
- Fly same track before and after for best comparison.
- Maybe a predetermined template with BDA radius, or a way to measure distance a bomb crater is from the target.
- I feel it serves a very good role for BDA.
- Good idea. Imagery could be taken back home to intell.
- Feel satellite might provide same information - might be unnecessary expense. For fixed targets would be useful but not this mission.
- Doesn't feel qualified to make suggestions on BDA.
- Would be very useful. Would prefer that it's maneuverable.
- Implement a "pipper" or graphic on-screen to aid operator, especially if he is only given a short time to view target area.

4. For what other types of missions do you think the SPI would result in an increase in mission success?

- Sea surveillance, troop concentrations, truck convoys, harbors, - target areas away from civilian areas. Dumb/iron bombs can still go off target due to bent fins, faulty release mechanisms, etc.
- Moving battlefield, i.e., Iraq. Armies of the march, relocatable command posts, airfield occupancy checks, harbor and shipping checks.
- Trans-shipping areas (road to rail, ship to road/rail), Troop concentrations/marshalling area, Natural choke points on a line of march, BDA after a Harpoon attack on a large combat task, BDA if

you are a subsequent sortie after the same target, Identify air defense against point targets.

- Sea surveillance and Harpoon missile deployment.
- Sea surveillance. Threat suppression with HARM shooters. Have one aircraft (B-52 bomber) high altitude as a path finder. The high altitude bomber stays out of the threat area, and relays SPI updated data to low altitude/high speed B-1Bs. By having path finders, it decreases workload on aircrews that must navigate to target while avoiding threats.
- Any visually significant target: bridges, dams, buildings, airfields, and relocatables. Other uses: ECM or relay to inbound aircraft data on local emitters.
- SCUD missiles, mobile launchers, troop and equipment concentration - any mobile targets.
- If SAC would allow crews to attack undesignated targets (SCUDS, SAM sites and let them program SRAMS then SPI would be a valuable asset for this type of scenario. Think SPI is a good idea - any place where there is a heavy concentration of targets in conventional mission.
- Any situation where you don't have sufficient recon imagery. Better for movable targets such as battlefield mission for air support. Naval vessels - ships that we have a general idea where they are and have SPI send LAT/LONG - then aircraft wouldn't have radar and indicate position.
- Fixed as well as mobile targets.